FALLOUT, RADIATION STANDARDS, AND COUNTERMEASURES

HEARINGS

BEFORE THE

SUBCOMMITTEE ON

RESEARCH, DEVELOPMENT, AND RADIATION

OF THE

JOINT COMMITTEE ON ATOMIC ENERGY
CONGRESS OF THE UNITED STATES

EIGHTY-EIGHTH CONGRESS

FIRST SESSION

ON

FALLOUT, RADIATION STANDARDS, AND COUNTERMEASURES

JUNE 3, 4, AND 6, 1963

Part 1

Printed for the use of the Joint Committee on Atomic Energy

U.S. GOVERNMENT PRINTING OFFICE

20-519 WASHINGTON : 1963

(The tables referred to follow:)

TABLE 1.—*Approximate fission and total yields of nuclear weapons tests conducted in the atmosphere by all nations*

[Yield in megatons]

Inclusive years	Fission yield		Total yield	
	Air	Surface	Air	Surface
1945 to 1951	0.19	0.52	0.19	0.57
1952 to 1954	1	37	1	59
1955 to 1956	5.6	7.5	11	17
1957 to 1958	31	9	57	28
Subtotal	37.8	54	69.2	104.6
1959 to 1960	(1)	(1)	(1)	(1)
1961	[2] 25		120	
Subtotal	63	54	189	105
1962	[2] 76		217	
Total	139	54	406	105

1 Test moratorium.
2 The small yield tests conducted in Nevada do not contribute significantly to the worldwide distribution of strontium 90 to which this summary is related.

TABLE 2.—*Approximate total and fission yields of atmospheric tests conducted in 1962*

[Yield in megatons]

	Fission yield	Total yield
United States	16	37
U.S.S.R.	60	180
Total	76	217

TABLE 3.—*Approximate fission yields injected into the stratosphere in 1961 and 1962*

[Yield in megatons]

	Lower stratosphere [1]	Upper stratosphere [1]	Total
U.S.S.R. (1961)	17	8	25
U.S.S.R. (1962)	30	30	60
United States (1962)	10	1	11

1 The lower stratosphere occupies the first few tens of thousands of feet above the tropopause and the upper stratosphere continues to about 150,000 feet. The tropopause, on the average, is located at 30,000–40,000 feet in the temperate and polar zones and 50,000–55,000 feet in the tropical and the equatorial zones. Debris injected above 150,000 feet is omitted from this table.

Representative PRICE. Thank you, Dr. Tompkins.

In reference to your explanation of the comprehensive document covering all the factors mentioned in your second to last paragraph, which has been prepared, I wonder if you could supply that for the record of the hearings of the committee?

Dr. TOMPKINS. With your permission, sir, I would prefer not to. This is in a preparatory state.

What I would like to submit for the record are the proposals which have been acted upon by the Council. These are still in the formative state at the present time. They are still in my office.

Representative PRICE. Would you submit what you think that you can reasonably submit to the committee?

exposure estimated as being attributable to fallout from all tests conducted through 1962. The corresponding genetically effective exposure attributable to medical practice is drawn from Dr. Lauriston Taylor's testimony of the 1962 hearings. If there is no sharp change in the annual average per capita exposure related to medical practice during the next 30 years the genetically effective dose would be between 900 and 1,500 millirems in 30 years; this is 9 to 15 times the exposure level attributable to fallout.

I. *Variation in natural background*

	Millirems per year
United States:	
Eastern seaboard	70–80
Colorado	150–200
Special areas:	
France	180–350
Northern Nile Delta	300–400
Kerala	1, 300
Localized areas	1, 000–12, 000

II. *Measured gamma dose rates in air inside buildings*

	Millirems per year	Millirems per 30 years	Difference between wood and other building materials (millirems per 30 years)
Austria:			
Wood	75–85	2, 250–2, 250	
Brick	95–105	2, 850–3, 150	600
Granite	105–140	3, 150–4, 200	900–1, 650
Sweden:			
Wood	75–85	1, 250–2, 550	
Brick	130–140	3, 900–4, 200	1, 650
Granite	185–230	5, 550–6, 900	3, 300

III. *Medical exposures* (*genetic*)

Millirems per year	30–50
Millirems per 30 years	900–1, 500

Representative HOSMER. Dr. Tompkins, you have introduced a new word here this year, the picocurie. Would you explain that term?

Dr. TOMPKINS. The picocurie is a little easier to say than micromicrocurie.

Representative HOSMER. It is just what we used to call a micromicrocurie?

Dr. TOMPKINS. Yes, sir.

Representative HOSMER. What is a picocurie?

Dr. TOMPKINS. One picocurie is one-millionth of a microcurie or 10 to the minus 12 curies.

Representative HOSMER. One-millionth of one-millionth of a curie?

Dr. TOMPKINS. Yes, sir. At a disintegration rate of 2.2 per minute, or thereabouts. It is a very, very small number.

Representative HOSMER. Thank you, Mr. Chairman.

Representative PRICE. Dr. Tompkins, in the FRC report released Saturday on page 26, paragraph 4.31, it is stated:

> The testing conducted in 1961 and 1962 probably produced about 100 times more carbon 14 than was produced naturally by cosmic rays during the same period.

Could you explain what this means, with a hundred times more of carbon 14 in the atmosphere than was there naturally.

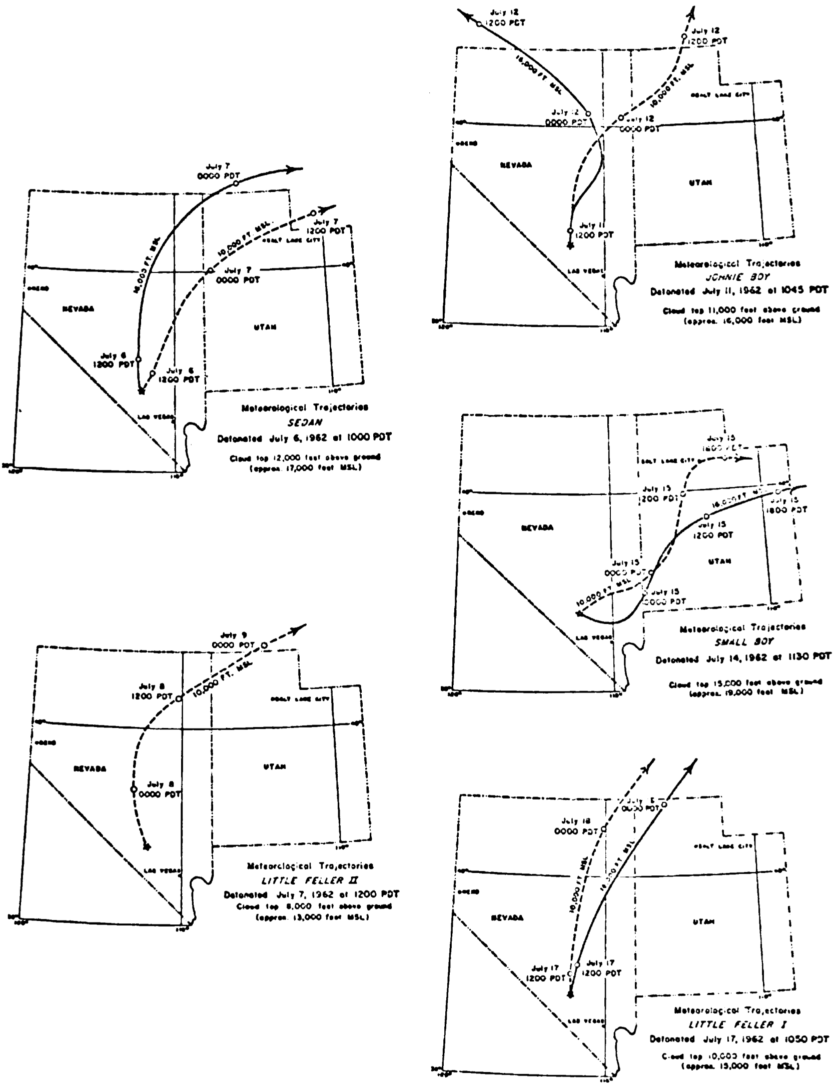


Figure 3.—METEOROLOGICAL TRAJECTORIES OF RADIOACTIVITY FROM NUCLEAR DETONATIONS

ESTIMATES OF RADIATION DOSES*

Gordon M. Dunning
Deputy Director
Division of Operational Safety
U. S. Atomic Energy Commission

Two time periods of testing were considered in preparing these estimates a) those nuclear tests conducted in 1962, and b) all past tests including 1962. There are uncertainties in these calculations as there are in all such estimates but it is likely that the total whole body and bone doses are correct within a factor of two. The calculations for the individual sources of exposure are less certain as is the one year exposures compared to the 30 and 70 year doses.

Estimates for whole body doses are based on individuals born prior to the start of nuclear testing, since these constitute the age group of highest exposure. On the other hand, estimates of bone and bone marrow doses are based on children born in 1963, since they represent the age group of highest exposure to these organs. Obviously, the two age groups are not identical.

The following factors were considered in estimating whole body doses: exposure from cesium-137 (internal and external), short-lived nuclides, and carbon-14. Bone doses were estimated by adding to the above, doses from internal strontium-90 and strontium-89. The levels

* I gratefully acknowledge the assistance in preparing these estimates to Mr. Tommy F. McCraw, Dr. Roy D. Maxwell, Mr. Alfred W. Klement, and Mr. James E. Miller.

of cesium-137 deposition were taken as 1.7 times the observed or predicted level of strontium-90 deposition. Estimates of dose contributions from short-lived nuclides were based upon an assumed age of fission debris in the stratosphere. Estimated doses were calculated making corrections for weathering, shielding and the movement of different radionuclides through the environment to man.

External exposures from cesium-137 were assumed to diminish with an effective half-time of ten years.[1.] Exposures to external short-lived radionuclides and short-lived internal emitters such as strontium-89 were considered to be completed essentially within about one year following periods of testing. It was assumed that strontium-90 is removed from that part of the biosphere which is important to man with an effective half-time of ten years.[1.] For calculations of 30 year and 70 year doses, it was assumed that carbon-14 would be reduced with a mean-time of 48 years or a half-time of 33 years.[1.]

Exposure estimates previously submitted for the U. S. population for tests through 1961 (Federal Radiation Council Report No. 3) were reevaluated from data on recent measurements of radionuclides in persons and in the diet. A review of the current data on measured levels of environmental radioactivity in 1962 indicated that the amount of fallout in 1962 was somewhat lower than had been predicted*. Estimates of whole body exposures from testing through 1961 based upon current data are closer to the lower limit of the predicted value of 30 year

*See Appendix

and 70 year exposures presented in the Federal Radiation Council Report No. 3.

Whole Body Exposures from All Tests Through 1961

	Based on Current Data	FRC Report No. 3
30 year	~63 mrem	60-130 mrem
70 year	~74 mrem	70-150 mrem

Estimates of Exposures from 1962 Tests

Estimates of exposures from 1962 tests were based upon U. S. Weather Bureau predictions of the fraction of fallout deposition expected during 1962, 1963 and 1964 from 1962 tests. These fractions have been applied to the most probable value of strontium-90 fallout for these three years, for the "wet" U. S. Predictions of cesium-137 deposition during these three years have been made from estimates of the strontium-90 fallout due to 1962 tests.

Strontium-90 For "Wet" U. S. *
(Millicuries per square mile)

Year	Yearly Deposition	Total accumulated (by end of year)
1961	-	85
1962	25 10 (1962 tests) 15 (past tests)	110
1963	50 40 (1962 tests) 10 (past tests)	160
1964	20 15 (1962 tests) 5 (past tests)	180
1965	10 5 (1962 tests) assumed 5(past tests) assumed	190

* In each year it is expected that about 70% of the annual strontium-90 fallout will occur in the first six months of the year. "Dry" United States has a value 1/2 to 1/3 of "wet" United States.

I. 30 and 70 Year Exposures From 1962 Tests
("Wet" U. S.)

A. Whole Body Exposure

1. External cesium-137 exposure

Assume: 70 mc/mile^2 of Sr-90

120 mc/mile^2 of Cs-137

1 mc/mile^2 of Cs-137 - - -> 0.03 mr/yr

Half-time of availability in environment - - ->

10 years

$$D_{30} = \frac{(120)\ (0.03)}{0.693/_{10}} \left[1 - e^{-\frac{0.693\ (30)}{10}} \right]$$

= 45 mrem

= 9 mrem (shielding factor of 5)[1].

D_{70} = 51 mrem

= 10 mrem (shielding factor of 5)

2. Internal Cesium-137 Exposure

Assume equivalent to external exposure[2]. (with a high percentage of the total dose delivered in the first year because of surface contamination).

3. Short-Lived Radionuclide Exposure

Assume: Six months residence half-time in the atmosphere in 1962. Ratio of 3 to 1[3.] doses from short-lived radionuclides versus Cs-137.

$$D_{30}\ (1962) = \frac{(17)\ (0.03)}{\frac{(0.693)\ (5)}{10}} \left[1 - e^{-\frac{0.693\ (30)}{10}} \right]$$

= 1.3 mrem (for Cs-137 including shielding)

= 1.3 x 3 = 3.9 mrem (for short-lived)

Assume: For 1963,

70% of annual fallout of Cs-137 occurs in first six months with a half-time of residence of six months.

$$D_{30}\ (1963) = \frac{(40)\ (0.7)\ (1.7)\ (0.03)}{\frac{0.693\ (5)}{10}} \left[1 - e^{-\frac{0.693\ (30)}{10}} \right]$$

= 3.6 mrem (for Cs-137 including shielding)

= 10.8 mrem (for short-lived)

Assume: For 1963

30% of annual fallout of Cs-137 occurs in last six months with ratio of 2 to 1.

D_{30} (1963) = 3.1 mrem (for short-lived)

Total = 17.8 mrem (for short-lived) (30 or 70 year)

4. Carbon-14 Exposures

Assume the initial dose rate from C-14 to be 0.0022[4] mr/yr per MT with a mean-time of 47.8 years or a half-time ($T_{1/2}$) equals 33 years. Initial dose rate=217 MT x 0.0022 mr/yr per MT = 0.48 mr/yr.

$$D_{30} = \frac{0.48}{\frac{0.693}{33}} \left[1 - e^{-\frac{0.693}{33}(30)} \right]$$

D_{30} = <u>10.7 mrem</u>

D_{70} = 17.6 mrem

(D_{∞} = 198 mrem using two reservoir models.[1])

B. <u>Bone and Bone Marrow Exposures</u>

1. Assume:

Year	Monthly Deposition Rate (R)	Cumulative (S)
1963	40/12 = 3.3	10 (deposited in 1962) + 20 (avg. for that deposited in 1963 = 30
1964	15/12 = 1.25	50 + 7.5 = 57.5

Milk levels of Sr-90 (yearly averages)

$M = 0.07\ S + 4.6\ R$[5]

For 1963 $M = 0.07\ (30) + 4.6\ (3.3)$

$= 17.3$ S.U. (strontium units)

For 1964 $M = 9.77$ S.U.

20-519 O - 63 (Part 1) - 16

Assume: Diet = 1.5 the levels in milk

Bone = 1/4 the levels in the diet

1963 Diet = 17.3 x 1.5 = 26 S.U.

Bone = 26 x 1/4 = 6.5 S.U.

1964 Diet = 9.77 x 1.5 = 14.6 S.U.

Bone = 14.6 x 1/4 = 3.7 S.U.

2. Dose to Bone from Sr-90

Assume dose to bone = 3 mr/yr per S.U. The 70 year dose to bone for a baby born in 1963 is:

Dose for one year at the 1963 bone level plus

Dose for 69 years at the 1964 bone level

The mean-life is assumed to be 14.4 years or

$T_{1/2}$ equals 10 years.

D 1st year = 6.5 x 3 = 19.5 mr

$$D\ 69\ \text{years} = \frac{3.75 \times 3}{0.693/10}\left[1 - e^{-\frac{0.693}{10}(69)}\right]$$

= 160.5 mr

D 70 years = 19.5 + 160.5 $\cong$ 180 mr

3. Dose to Bone from Sr-89

Assume: Ratio $\frac{Sr\text{-}89}{Sr\text{-}90}$ for 1st year = 2[6].

D = 2 x 19.5 mr = 39 mr

(Most of this dose is delivered in the first year)

4. Dose to Bone Marrow from Sr-89 and Sr-90

Assume: That the dose to bone marrow equals 1/3 the dose to bone from Sr-89 and Sr-90.

$D_{70} = 1/3 \times 219 = 73$ mrem.

Summary

Estimated Radiation Doses in the "Wet" U.S. from 1962 Tests*

Tissue or organ	1 year (mrem) (1963)	30 year (mrem)	70 year (mrem)
Whole body and reproductive cells			
Cs-137 external	0.3	9	10
Cs-137 internal	9.0	9	10
Short-lived radionuclides	14.0	18	18
C-14	0.5	11	18
Total	23.8	47	56
Bone			
Sr-90	20		180
Sr-89	39		39
Whole body	24		56**
Total	83		275
Bone Marrow			
Sr-90	6.7		60
Sr-89	13.0		13
Whole body	24.0		56**
Total	43.7		129

* Values for "dry" U.S. are about one-half to one-third the values for "wet" U. S.

**C-14 dose values may be slightly higher for bones than for whole body.

II. 30 and 70 Year Exposures From All Past Tests ("wet" U. S.)

A. Whole Body Exposures

Whole body exposures consist of exposures from past tests through 1961 (Federal Radiation Council Report No. 3), plus the exposures from the 1962 tests except for the one year doses that are considered individually.

	1 Year	30 Year	70 Year
Tests through 1961	10	63	74
1962 tests	24	47	56
		110	130

B. Bone and Bone Marrow Exposures

1. Assumption

The age group expected to receive the highest bone dose from all tests through 1962 is babies born in 1963. The bones of these children will have been formed in a year (1963) of the highest deposition rate of strontium-90. The estimated bone dose, therefore, applies to this age group. On the other hand, the age group expected to receive the highest whole body exposure will be those persons born prior to the beginning of testing. To insure that highest estimates are used, the calculations for bone doses and whole body doses are made for the age group with the largest values, even though the two sets of doses (bone and whole body) do not apply to the same age group.

2. Doses from Strontium-90

Predictions of strontium-90 content in bones of children in the indicated age groups for 1963, 1964 and 1965 were furnished by the Health and Safety Laboratory, New York Operations Office. The following values were supplied:

Sr-90 Content in Bones of Children
(pc Sr-90/gram Ca)

Year	0-4 Year		1963 Baby	
	Wet	Dry	Wet	Dry
1963	5	4	12	9
1964	7	4		
1965	7	4		

Assume 12 strontium units (SU) in the bones of babies born in 1963 in "wet" U. S. and seven SU in bones of children one to two years of age in 1964 and 1965 with a half-time for strontium of ten years.

a. 1963 one year dose from strontium-90:

12 SU x 3 mrem per year per SU = 36 mrem

b. 1964 sixty-nine year dose from strontium-90:

$$D_{69} = \frac{7 \text{ SU x 3 mrem/year per SU x 1}}{\frac{0.693}{10}} \left[1 - e^{-\frac{0.639(69)}{10}} \right]$$

D_{69} = 300 mrem

D_{70} = 36 + 300 = 336 mrem

3. Strontium 89-90 doses

Seventy year dose to bone from strontium-89 equals 39 mrem (same as for 1962 tests).

Seventy year dose from strontium-89 and strontium-90 equals:

336 + 39 = 375 mrem

4. Whole body and genetic exposure

Determine the whole body and genetic exposure from cesium-137 (internal and external), short-lived and carbon-14, for all tests through 1962. (Determined for a baby born in 1963 to be added to the strontium-89 and strontium-90 doses to determine total bone dose.)

a. Seventy year external exposure Cs-137

$$D_{70} = \frac{(110 + 50 + 20 + 10)\ (1.7)\ (0.03)}{\frac{0.693(5)}{10}} \left[1 - e^{\frac{-0.693(70)}{10}} \right]$$

$$D_{70} = 27.7 \text{ mrem} \cong 28 \text{ mrem}$$

b. Seventy year internal exposure Cs-137

Assume internal dose equals external dose (from fallout in 1963 and afterwards).

$$D_{70} = 10 \text{ mrem}$$

c. Seventy year exposure from short-lived nuclides (same as for 1962 tests)

$$D_{70} = 10.8 + 3.1 = 13.9 \text{ mrem (1963 onward)}$$

d. Seventy year dose from C-14

$$D_{70} = \frac{459 \text{ MT} \times 0.0022}{\frac{0.693}{33}} \left[1 - e^{\frac{-0.693(70)}{33}}\right]$$

D_{70} = 37.0 mrem

(D_{∞} = 420 mrem)

5. Summation

Seventy year dose to bone for baby born in 1963 from cesium-137 (internal and external), short-lived and strontium-89 and strontium-90, and carbon-14 will be:

D_{70} = 28 + 10 + 14 + 375 + 37 = 464 mrem

Seventy year dose to bone marrow will be:

D_{70} = 28 + 10 + 14 + 1/3(375) + 37 = 214 mrem

Summary

Estimated Radiation Doses from All Past Tests.* ("Wet" U.S.)

Tissues or Organs		Dose (mrem)**
Whole body and reproductive cells		
	30 year	110
	70 year	130
Bone	70 year	464**
Bone marrow	70 year	214

*Dose "dry" U. S. is 1/3 to 1/2 the dose in "wet" U. S.

**Note that the 70 year dose to bone is not equal to the sum of the bone dose from strontium-89 and strontium-90 from all tests through 1962, plus the 70 year whole body and reproductive cells exposure shown above. The whole body and reproductive cells exposure for 70 years applies to persons born prior to testing. The bone dose shown above applies for babies born in 1963 and includes exposures to strontium-90 (from all tests) that enters the food chain subsequent to 1962, plus strontium-89 and short-lived radionuclides from 1962 tests, and carbon-14 from all tests through 1962.

III. One Year Whole Body Exposure from 1962 Tests

A. External Cesium-137 Exposure

The one year dose in 1963 from 1962 tests will consist of exposure to fallout accumulated in 1962 from 1962 tests plus exposure to fallout in 1963 from 1962 tests. Assuming 70% of the 1963 fallout occurs during the first six months, an average value for the year may be determined.

cesium-137 deposition in 1962 from 1962 tests equals 17 mc/mi^2

cesium-137 deposition in 1963 from 1962 tests equals 68 mc/mi^2

70% occurs in first six months 1963 equals $0.7 \times 68 = 47.6$ mc/mi^2

30% occurs in last six months 1963 equals $0.3 \times 68 = 20.4$ mc/mi^2

For the first six months:

$(47.6)\ (0.03)\ (mr/yr) = 1.4$ mrem

For second six months (with six months duration to extend to end of one year):

$(20.4)\ (0.03)\ (0.5 \text{ year}) = .31$

Total $= 1.4 + 0.31 = 1.7$ mrem

with shielding $= 0.3$ mrem total

B. Internal Cesium-137 Exposure

Assume equivalent to external cesium-137 exposure for 30 years, i.e., 9 mrem.

C. Short-lived Radionuclide Exposures

Exposures in 1963 from 1962 tests will be the same as previously predicted.

Dose from fallout during the first half 1963 equals 10.8 mrem

Dose from fallout during second half 1963 equals 3.1 mrem

Total $= 10.8 + 3.1 = 13.9$ mrem

D. Carbon-14 Exposure

One year C-14 dose in 1963 from 1962 tests will be:

$$D_1 = \frac{217 \times 0.0022}{\frac{0.693}{33}} \left[1 - e^{\frac{-0.693(1)}{33}} \right]$$

$$D_1 = 0.46 \text{ mrem}$$

Summary

Estimated One Year Whole Body Exposures in 1963 from 1962 Tests ("wet" U.S.)

Cs-137 (external)	0.3 mrem
Cs-137 (internal)	9 "
Short-lived	14.0 "
C-14	0.5 "

APPENDIX

30 and 70 Year Exposures From All Tests Through 1961 ("wet" U.S.)

A. The lower value of predicted whole body dose in Table 1, Federal Radiation Council Report No. 3, most closely approximates the dose from all tests through 1961. This is suggested by measurements of fallout deposition and the calculations that follow.

This assumption is supported by the following dose estimates for all tests through 1961 based upon recent fallout measurements.

B. Thirty-year Exposures

1. Cesium-137 External exposure

Assume:

Deposition of Sr-90 (accumulated) as of January 1, 1963	110 mc/mi^2
Deposition of Sr-90 in 1962	25 mc/mi^2
60% of 1962 deposition is from tests prior to 1962	15 mc/mi^2
Deposition through 1962 (accumulated) from tests prior to 1962	100 mc/mi^2
Deposition of Cs-137 (accumulated from tests through 1961) 1.7 x 100	170 mc/mi^2

$$D_{30} = \frac{170 \times 0.03}{\frac{0.693(5)}{10}} \left[1 - e^{\frac{-0.693(30)}{10}} \right]$$

$$D_{30} = 12.8 \text{ mrem}$$

2. Cesium-137 Internal Exposure

Assume internal exposure equals the external exposure.

$D_{30} = 12.8$ mrem

3. Short-lived exposure

Assume the ratio of short-lived exposure to Cs-137 external is 2/1.[7]

$D_{30} = 2 \times 12.8 = 25.6$ mrem

4. Carbon-14 Exposure

Total yield through 1961 equals 122 MT air equivalent (through 1958) plus 120 MT (USSR 1961 tests) equals 242 MT.

$$D_{30} = \frac{242 \times 0.0022}{\frac{0.693}{33}} \left[1 - e^{-\frac{0.693}{33}(30)} \right]$$

$D_{30} = 11.8$ mrem

Summary

30 Year Whole Body Exposures From Tests Through 1961

Cs-137 (external)	12.8 mrem
Cs-137 (internal)	12.8 mrem
Short-lived	25.6 mrem
C-14	11.8 mrem
Total	63.0 mrem

Federal Radiation Council Report No. 3 (lower value) presents 60 mrem whole body and genetic exposure from tests conducted through 1961.

C. Seventy-year Exposure

1. Cesium-137 External Exposure

$D_{70} = 14.5$ mrem

2. Cesium-137 Internal Exposure

$D_{70} = 14.5$ mrem

3. Short-lived Exposure

Assume seventy year exposure equals the thirty year exposure

$D_{70} = 25.6$ mrem

4. Carbon-14 Exposure

$D_{70} = 19.6$ mrem

Summary

70 Year Whole Body Exposure From Tests Through 1961

Cs-137 (external)	14.5 mrem
Cs-137 (internal)	14.5 mrem
Short-lived	25.6 mrem
C-14	19.6 mrem
Total	74.2 mrem

Federal Radiation Council Report No. 3 (lower value) presents 70 mrem whole-body and genetic exposure from tests conducted through 1961.

Estimate of Radiation Doses from Radioiodine

The estimation of thyroid doses from radioiodine has been assigned to others.

REFERENCES

1. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation. Supplement No. 16 (A/5216). 1962.

2. The observed data of cesium-137 in man is lower than this estimate. The United Nations Report suggests a somewhat higher ratio of exposure from internal versus external cesium-137.

3. "Shorter-Lived Fission Products in Fallout", Dunning, G. M. Health Physics. Vol. 4, pp. 35-41. 1960.

4. Radiation Standards, Including Fallout. Hearings before the Joint Committee on Atomic Energy, Congress of the United States. 1962 p. 830.

5. Based on Health and Safety Laboratory estimates.

6. For peak years, the ratio of strontium-89 to strontium-90 activity in milk is three to four. Considering the different energies, the ratio of dose rates might be about two. The United Nations Report suggests about the same values for 1958.

7. Fallout From USSR 1961 Nuclear Tests. Dunning, G. M. TID-14377. 1962.

SUMMARY STATEMENTS

Dr. DUNNING. (1) The nuclear tests (by U.S.S.R. and the United States) during 1962 released about two-thirds as much fission products as all tests through 1961 (76 versus 117 megatons). Since fission products introduced into the atmosphere at the more northerly latitudes result in more deposition in the North Temperate Zone than from tests in the equatorial latitudes, the U.S.S.R. tests probably will account for about three-fourths of the long-term fallout in the United States.

(2) Since nuclear tests began, the fission products scattered globally from the U.S.S.R. tests amount to somewhat more than twice that of the United States and United Kingdom (110 versus 51 megatons). Since fission products introduced into the atmosphere at the more northerly latitudes result in more deposition in the North Temperate Zone than from tests in the equatorial latitudes, the U.S.S.R. tests probably will account for about three-fourths of the long-term fallout in the United States.

(3) The total yields (of interest in carbon 14 production) from the 1962 tests amounted to about 217 megatons of which 83 percent originated from the U.S.S.R. tests. Since the year that tests began there has been about 511 megatons total yield of which about 70 percent originated from U.S.S.R. tests.

(4) The estimated 30-year whole body dose from the 1962 tests in "wet" United States (the areas of highest fallout) is estimated to be 47 millirem and from all past tests about 110 millirem. The 110 millirem dose is about one-thirtieth, that is, 3 percent of the whole body exposure received during the same period of time (30 years) from natural background.

(5) The estimated 70-year bone dose to the age group receiving the highest exposure (individuals born in 1963) from the 1962 tests is estimated to be about 275 millirem and from all past tests about 465 millirem. The 465 millirem dose is about one-twentieth, that is, 5 percent of the bone dose received during the same period of time (70 years) from natural background.

(6) The difference in natural background radiation levels at various localities can be much greater than 5 percent, that is, the 70-year dose to bones from fallout can be less than the variation in natural background from place to place over the same period of time.

(7) The above estimates of doses are likely to be correct within a factor of two. They are based on "wet" United States: "dry" U.S. values may be one-half or less than these values.

Both the estimated whole body and bone doses from all past tests are less than anticipated in the Federal Radiation Council's Report No. 3, principally because the observed fallout levels and the bone levels of strontium 90 are less than estimated previously.

The whole body dose is based on individuals born prior to nuclear testing while the bone dose is based on individuals born in 1963. This was done to maximize the estimated dose in each category, although they obviously do not apply to the same individual.

The estimation of thyroid doses from radioiodine has been assigned to others.

I would like to digress just a moment. Yesterday there was some discussion on this variation. I do not have the precise numbers

The effect of processing operations on the removal of strontium 90 from raw foods

FREEZING AND CANNING

Product	Strontium 90 concentration, picocuries per kilogram		Contamination removed by processing, percent
	Raw	Processed	
Carrots	6.2	5.0	19
Snap beans	16.0	6.1	62
Spinach	23.0	18.0	22
Tomatoes	1.4	1.1	21
Peaches	1.4	.7	46

MILLING

	Raw	Flour	Contamination removed by processing, percent
Wheat	22	4.4	77
Rice	4.9	.7	86

FDA is now engaged in collaborative studies with the National Canners Association and the Association of Frozen Food Packers to examine in pilot and normal full-scale commercial operations the processing steps involved in the production of standard canned food and frozen food items from the raw counterparts. Many of the steps involved in the commercial preparation of canned foods and frozen foods may be amenable to certain modifications that would be more effective in removing radioactive contamination.

For example, in the washing of spinach in preparation for canning or freezing, the use of certain detergents are being studied as to their suitability for more effective or complete removal of contamination.

Recently we have been conducting a whole diet study for the purpose of determining what the radioactivity level is in a representative diet as prepared for consumption. The diet employed in this study is one that would represent the food consumption of a 19-year-old boy. The data obtained yield valuable information as to the reduction in radioactive contamination brought about in the normal preparation of foods for consumption. For instance, about 6 percent of the food products as purchased go into the garbage as peelings, trimmings, bones, and so forth, and this discarded portion contains approximately half of the strontium 90 activity.

These various studies have provided essential facts as to the problem of radioactive contamination and point to areas where countermeasures may be effective in protecting or salvaging food commodities.

Representative PRICE. Thank you very much, Mr. Roe.

Dr. TOMPKINS. I would like, Mr. Chairman, now to call on Mr. Clarkson, Department of Agriculture.

Dr. CLARKSON. Mr. Chairman, with your permission, I suggest that my prepared statement be made a part of the record (see p. 314). Since some of the items already have been alluded to by Dr. Chadwick, I would like to make only a brief summary at this time.

Representative PRICE. Very well.

Dr. CLARKSON. Research on protective measures in the Department of Agriculture is designed to minimize the consumer's intake of radio-

APPENDIX 13

(Prepared by JCAB staff, July 1963)

Summary of total and fission yields, 1945–62

[In megatons]

Year	Approximate yields, United States and United Kingdom		Approximate yields, U.S.S.R.	
	Total	Fission	Total	Fission
1945–58	124	66	50	26
1961	(1)	(1)	120	25
1962	37	16	180	60
Total	161	82	350	111

[1] Negligible; predominantly low yield underground tests conducted by United States at the Nevada test site.

Comparison of yields of tests conducted before and after moratorium

[In megatons]

	United States and United Kingdom		U.S.S.R.	
	Total	Fission	Total	Fission
1945–58	124	66	50	26
1961–62	37	16	300	85

APPENDIX 14

GREATER ST. LOUIS CITIZENS' COMMITTEE FOR NUCLEAR INFORMATION,
St. Louis, Mo., June 5, 1963.

Hon. MELVIN PRICE,
Chairman, Subcommittee on Research, Development and Radiation,
Joint Committee on Atomic Energy, Congress of the United States,
Washington, D.C.

DEAR CONGRESSMAN PRICE: We appreciate the opportunity of once again submitting testimony before the Joint Committee on Atomic Energy, which has rendered such invaluable services by making available exhaustive evidence and interpretations on radioactive environmental contamination.

One important result of the hearings held June 4–7, 1962, was the committee's attempt to obtain clarification of the applicability of radiation protection standards. In his capacity of Chairman of the Federal Radiation Council (FRC), Mr. Anthony J. Celebrezze replied in a letter of August 17, 1962, but instead of clarifying the matter, Mr. Celebrezze's statement introduced extraordinary confusion, and this confusion persists.

Before Mr. Celebrezze's reinterpretation, it was generally assumed that the radiation protection guides (RPG) are applicable to the present situation. The FRC now holds that we are not currently engaged in "normal peacetime operations" and that the RPG's were developed specifically "in connection with the industrial use of ionizing radiation." This flatly contradicts the FRC staff report (May 13, 1960) in which only "major nuclear accidents" are specifically excluded from peacetime uses. In addition, the USPHS, a division of Mr. Celebrezze's Department of Health, Education, and Welfare, has consistently referred to the RPG's with reference to fallout. (For example, press releases dated Nov. 24, 1961; Feb. 20, 1962; May 24, 1962; and Aug. 17, 1962.)

The FRC can, of course, reinterpret the applicability of its recommendations, but endless public confusion could have been avoided by a frank statement that the interepretation had been changed. It is doubtful, however, whether the FRC can with impunity fail to discharge its lawful obligations; it is charged by

FALLOUT, RADIATION STANDARDS, AND COUNTERMEASURES

HEARINGS

BEFORE THE

SUBCOMMITTEE ON RESEARCH, DEVELOPMENT, AND RADIATION

OF THE

JOINT COMMITTEE ON ATOMIC ENERGY CONGRESS OF THE UNITED STATES

EIGHTY-EIGHTH CONGRESS

FIRST SESSION

ON

FALLOUT, RADIATION STANDARDS, AND COUNTERMEASURES

AUGUST 20, 21, 22, AND 27, 1963

PART 2

Printed for the use of the
Joint Committee on Atomic Energy

U.S. GOVERNMENT PRINTING OFFICE
20-519
WASHINGTON : 1963

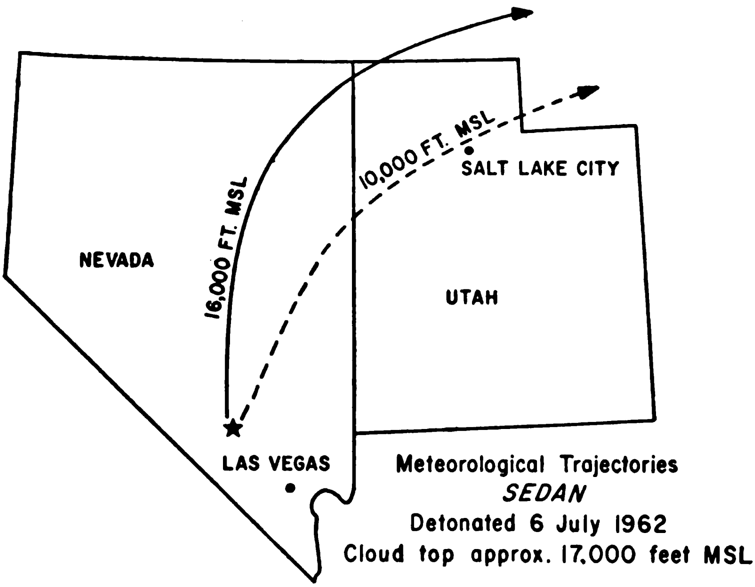


FIGURE 1.—Meteorological trajectories of the Sedan shot (from Bostrom).

Figure 1 is a map of Utah and Nevada. Superimposed on this map are the meteorological trajectories for the Sedan shot. One trajectory is for 16,000 feet altitude above mean sea level, and the other, for 10,000 feet mean sea level. The altitude we are interested in, of course, is not 10,000 feet in the air; it is on the ground, which in Utah is generally about 5,000 feet above mean sea level.

Because all of the subsequent Nevada weapons tests in July 1962 also carried fallout into Utah, we had just about given up hope of finding the true deposition pattern from Sedan until I happened to learn, 11 months after the incident, of the inclusion of this radioactive tungsten. When we found out that there was radioactive tungsten incorporated in the Sedan shot, we were able to analyze samples of hay and pasture grass, that had been collected during this time, and find the actual deposition pattern on the ground.

The highest deposition pattern was not under the meteorological trajectories shown in figure 1. The highest deposition pattern we found from Sedan was east of Salt Lake City in the milk-producing area near Snyderville. This points out a limitation to the use of meteorological trajectories for predicting fallout deposition. The Weather Bureau has developed a better method. It is the UF plot, or upper air fallout plot which indicates what is on the ground.

My point is this: It would be much more meaningful if fallout trajectories were expressed in terms of what is on the ground instead of what is up in the air.

Figure 2 shows the trajectories of the Small Boy shot. We found our highest levels of contamination in the Uintah Basin near Duchesne. Unfortunately we did not have monitor stations near the Provo area where apparently the track moved prior to reaching the Duchesne

area where we found the highest levels. Thus, I have no assurance that we were able to find the highest levels that actually occurred.

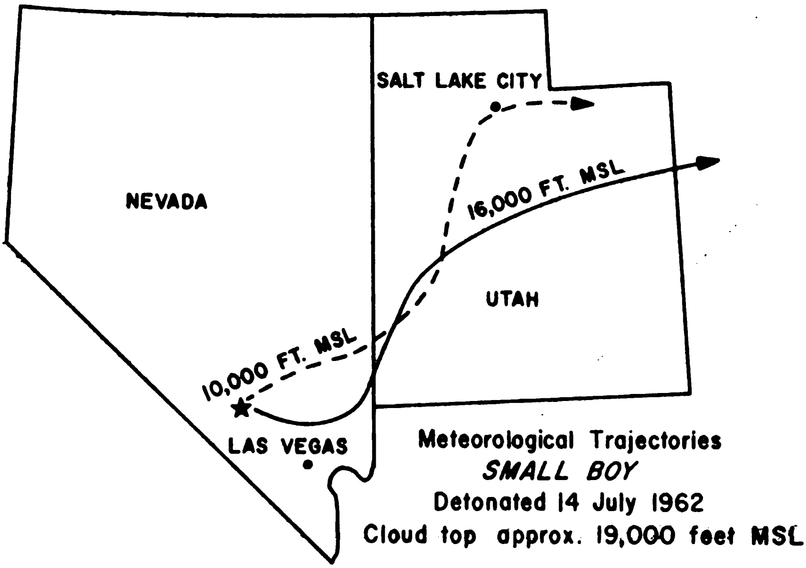


FIGURE 2.—Meteorological trajectories of the Small Boy shot (from Bostrom).

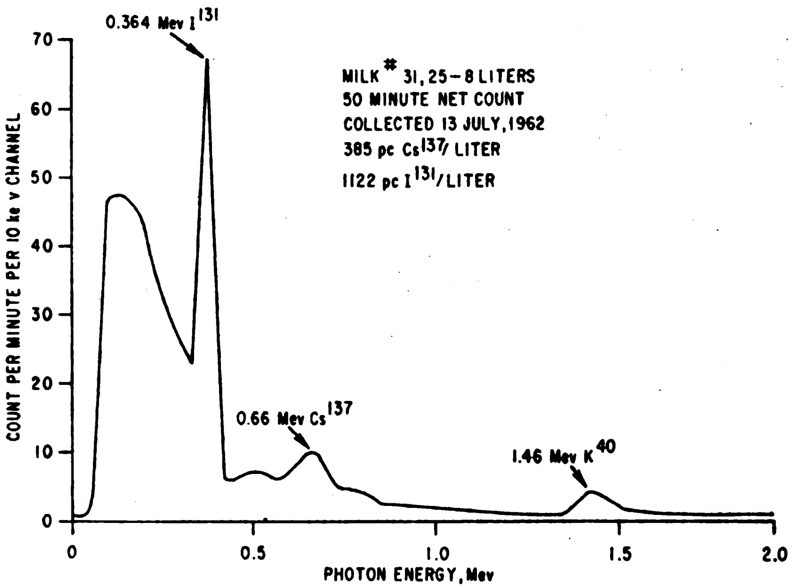


FIGURE 3.—Gamma-ray spectrum of the first milk sample analyzed during the 1962 iodine–131 incident.

A few days after Dr. Pendleton discovered the incident, he collected milk samples and brought them into our lab. I have inside an iron room a giant sodium iodide crystal gamma ray spectrometer coupled to a 400-channel analyzer. We analyzed milk for gamma activity with this spectrometer.

There were three prominent gamma ray peaks. The peak at 1.46 Mev. was due to naturally occurring potassium 40. We also had a peak at 0.66 Mev. which was due to fallout cesium 137, and the relative heights of these are about what we would have expected due to Soviet testing and to our own testing in the spring of 1962.

But dwarfing these peaks is an enormous peak that is due to iodine 131. This was not by any means the highest level which was discovered. This was the first sample we analyzed. It had been collected on July 13. It contained a little better than 1,000 picocuries of iodine 131 per liter at the time of assay.

Figure 4.—Map of Utah showing the locations of Pendleton's milk farms. The yearly radiation protection guide of 36,500 p.c. I^{131} intake was exceeded by persons drinking 1 liter of milk per day from the stations marked with stars.

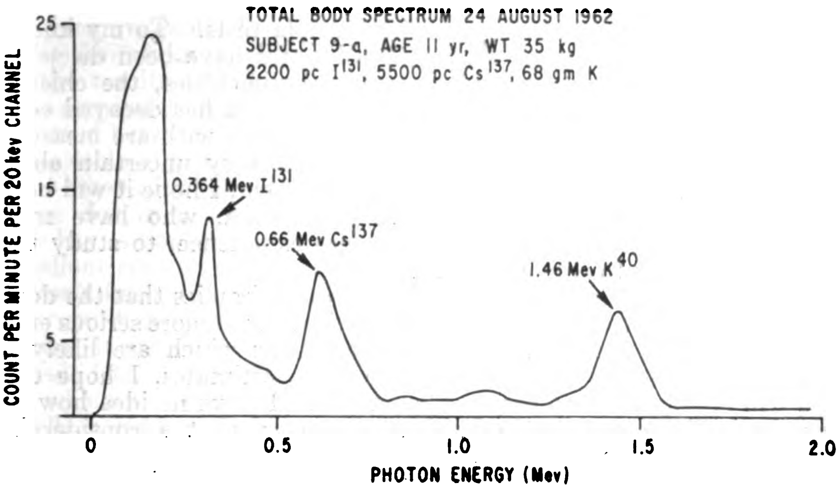


Figure 8.—Total body spectrum of an 11-year-old girl. Iodine-131 was still prominent although over 4 half-periods of iodine-131 had elapsed since its concentration in milk had reached its peak.

Figure 8 shows the total-body spectrum of an 11-year-old girl. The peak at 1.46 Mev is due to her natural potassium-40. This is proportional to the amount of muscle in her body. The peak at 0.66 Mev is due to her cesium-137, which distributes in a similar fashion to the potassium, in other words, mainly in the muscle although it occurs in all tissue. The peak at 0.36 Mev is due to her iodine-131.

I would like to emphasize a point. When this girl was measured, more than four half-periods of iodine-131 had elapsed from the time that the iodine in the milk reached its maximum concentration. Yet her iodine-131 peak is still quite evident.

The peaks, however, can be somewhat misleading. Whereas the radiation from the potassium and the cesium is absorbed more or less uniformly throughout all of the body, in the case of iodine, it is concentrated in an extremely small amount of tissue. In the infant child, the estimated weight of the thyroid is about two grams, which would be roughly half the weight of the end of my little finger if I chopped it off at the first joint. Virtually the whole body burden of iodine 131 is concentrated in an extremely small volume.

Representative Holifield. Let me ask one further question. The first tall peak there was an extrapolation of the total body measurement, was it not?

Dr. Mays. The unlabeled low-energy peak in figure 8 is a scatter peak. It results from incomplete absorption in the crystal of a gamma ray's energy. Some gamma rays lose part of their energy in getting out of the person's body, some scatter off the walls of the iron room before reaching the crystal, and some scatter back out of the crystal. Thus, the scatter peak is lower in energy than the full-energy peak.

Representative Price. Would you proceed, Doctor, please?

Senator BENNETT. So this 8.6 could not be the total exposure on one day.

Dr. MAYS. No; it is the exposure for the entire year.

Senator BENNETT. Yes.

Dr. MAYS. Just before you came in, Congressman Holifield asked the same question.

Representative HOLIFIELD. I was exploring this same question.

Senator BENNETT. OK.

TABLE 5.—*Summary of dose estimates*

Year of tests	Utah infants under 2 years	Estimated average thyroid dose (rad)—		
		from air	from yield	mean
1951	40,000	(1)	0.4	0.4
1952	41,000	5.9	1.6	3.8
1953	43,000	(1)	6.3	6.3
St. George	700	68	------------	68
1955	45,000	(1)	2.0	2.0
1957	47,000	8.6	8.6	8.6
1958	48,000	1.4	1.4	1.4
1962	53,000	1.0	(1)	1.0

1 Not available.

Dr. MAYS. In table 5, I have combined the estimates from the other tables to establish what the estimated exposure was for each year. In addition to tabulating the doses, I have also listed the number of children between zero and 2 years of age that were living in Utah during this time. There was one additional incident that I did not mention, and perhaps should have, and that was the 1953 St. George incident. In 1953, St. George had very high levels of radioactive fallout, and based on the air beta concentration, I have calculated an average thyroid dose of 68 rads for the 700 infants in the St. George region.

Now, this 68 rads may be subject to error. Perhaps it is in error by as much as a factor of 4, but I don't know whether it is high by a factor of 4 or whether it is low by a factor of 4. A recent analysis of this fallout iodine problem made by Dr. Harold Knapp has been released by the AEC, and in this, he has used a different method than I have used. He has used what I consider to be a much better method, and I would have used his method myself if I had had the data available at the time.

Knapp assumed that iodine 131 exposure is proportional to the gamma activity that falls onto the pasturelands. Using Knapp's method, the thyroid doses for the St. George area would range somewhere in the neighborhood of 120 to 440 rads. My 68-rad value is below the lower range of Knapp's estimations.

However, it may be that Knapp's figures are somewhat higher than the actual exposures, because he has calculated for the worst possible case. By this, I mean cattle either eating fresh pasturage or cattle being fed fresh hay that is cut each day.

In actuality, many of the farms in Utah use stored feed the year round, and in this case, their milk would be much less contaminated.

Senator BENNETT. By this time, the infants who were exposed in 1953 in St. George are 10 to 12 years old.

Dr. MAYS. That is correct.

TABLE 2.—*Thyroid dose estimates from air beta concentrations*

Year of tests	Sum of peak adjusted air concentrations (pc/m³)	Estimated average infant thyroid dose (rad)
1951	(?)	(?)
1952	[1] 21,000	5.9
1953	(?)	(?)
St. George	240,000	68.0
1955	(?)	(?)
1957	30,450	8.6
1958	4,872	1.4
1962	3,522	[2] 1.0

[1] Time after burst not given: [a] assumed by me to be 1 day.
[2] Calculated from measured I^{131} in milk.

[a] G. M. Dunning, "Radiation Exposure From Nuclear Tests at the Nevada Test Site," Health Physics Journal 1: 3, 255–267 (1958).

Uncertainties include (*a*) how consistently a single air sampler can monitor different fallout trajectories, (*b*) how long it was from burst to assay in the 1952 shots, (*c*) how dairy farming practices in St. George correspond to those for the State as a whole, (*d*) how much the air beta values for 1962 were increased by neutron-activated tungsten in the "Sedan" shot,[12] and (*e*) how accurately our calculated thyroid doses for 1962 represented the true State average.

Thyroid dose estimates from fission yield

The air data available to me did not permit estimation of thyroid exposures in 1951, 1953, and 1955. Therefore, a different method of estimation was used to fill in these gaps and to cross-check, when possible, the estimates based on air concentrations. I^{131} exposure was assumed to tend to be roughly proportional to fission yield. The 1962 fission yields were not available (perhaps for valid security reasons). Therefore, the dose estimates were normalized to the 1957 value of 8.6 rad previously estimated by the air concentration method. Dose estimates from fission yield are shown in table 3. Fission yields were taken from "The Effects of Nuclear Weapons, 1962"[13] and are for the period between April 1 and October 31 when hay grows in Utah.

TABLE 3.—*Thyroid dose estimates from fission yield*

Year of tests	Kiloton yield (Apr. 1–Oct. 31)	Estimated average infant thyroid dose (rad)
1951	18	0.4
1952	64	1.6
1953	252	6.3
1955	84	2.0
1957	344	[1] 8.6
1958	57	1.4
1962	(?)	1.0

[1] Estimated from the 1957 and 1962 air beta concentrations and the 1962 computed dose.

Additional limitations to this method are inconsistencies in the direction taken by fallout and variations in its rate of descent. For a large number of tests such differences should tend to cancel out.

Summary of dose estimates

Dose estimates for the air beta and yield methods are combined in table 4. Populations were computed from the 1950 and 1960 U.S. censuses.

[12] W. B. Lane; some radiochemical and physical measurements of debris from an underground nuclear detonation, Project Sedan report PNE-229-P, 53 pages (May 15, 1962).
[13] S. Glasstone (ed.), "The Effects of Nuclear Weapons, 1962," U.S. Government Printing Office, see pp. 671–681 (1962).

TABLE 4.—*Summary of dose estimates*

Year of tests	Utah infants under 2 years	Estimated average thyroid dose (rad)		
		From air	From yield	Mean
1951	40 000	(?)	0.4	0.4
1952	41,000	5.9	1.6	3.8
1953 [1]	43,000	(?)	6.3	6.3
1955	45,000	(?)	2.0	2.0
1957	47,000	8.6	8.6	8.6
1958	48 000	1.4	1.4	1.4
1962	53,000	1.0	(?)	1.0

[1] St. George, Utah, infants under 2 years, 700; estimated average thyroid dose (rad): from air, 68; from yield, none; mean, 68.

Recognizing that some children were exposed at age 0–1 and again at age 1–2, approximately 250,000 Utah children have been exposed to crudely estimated average thyroid doses of 4.4 rad prior to age 2. Individual doses of course range from much higher to much lower. Despite uncertainties in these dose estimates the large number of exposed children suggest that a statewide study for possible delayed effects should be considered.

The information needed to refine these dose estimates includes the fission yields for the July 1962 tests, and air beta data for 1951, 1952, 1953, and 1955. In addition, it would be most helpful if data were available on the increase in gamma activity on the ground following previous tests. These gamma results would provide an additional, and probably superior, method of dose estimation.

Forgive me if these estimates are less complete than desired. To my knowledge this is the first time an attempt to evaluate Nevada I^{131} exposure through the food chain has been discussed openly. When things are done for the first time the result is frequently a bit unpolished.

3. HOW TO REDUCE I^{131} EXPOSURE

Continued weapons development is essential for the safety of this Nation. Some radiation exposure is a small price to pay for liberty. It would indeed be poor economy to lose a nuclear war because our weapons testing program had been needlessly hampered. I believe that no test needed for national defense should be canceled. However, a number of measures can be taken to protect the public from I^{131} overexposure during essential weapons testing:

(*a*) Test large yield devices outside of the continental United States; i.e., in the Pacific.

(*b*) Schedule shots for late autumn or winter when possible to prevent heavy contamination of growing plants.

(*c*) Improve prediction of fallout trajectories before detonation.

(*d*) Report explosion time, weapon size, and fallout trajectory to health departments and research organizations so that corrective action, if necessary, can be effective.

(*e*) Increase monitoring of milk for I^{131} when the gross beta activity in the air exceeds a limit, such as 100 picocuries per cubic meter.

(*f*) Divert milk exceeding a limit such as 1,000 picocuries I^{131} liter from the fluid market to the manufacture of cheese and other long shelf life products.

(*g*) Recommend powdered or canned milk for infants and pregnant women until I^{131} in fresh milk returns to acceptable levels.

(*h*) Use uncontaminated stored feed to hasten the reduction of I^{131} in milk to acceptable concentrations.

(*i*) Agree on radiation protection guides which apply to fallout.

Control of unnecessary radiation exposure from whatever source is a sound principle. Corrective measures may again need to be taken by those responsible for the safety of the public.

A REPORT ON THE IODINE 131 HAZARD FROM SHORT-RANGE FALLOUT PRODUCED BY NUCLEAR TESTS AT THE NEVADA TEST SITE

1) The problem

This report is an inquiry into the hazard resulting from exposure of local populations, especially in the vicinity of the Nevada Test Site to iodine 131 in fallout produced by nuclear explosions at that site.

At the hearings of the Joint Congressional Committee on Atomic Energy held in 1957, Dr. Lyle Alexander summarized the iodine 131 hazard briefly: "For a period of days following a heavy deposition of fresh fallout, iodine 131, which has a half life of 8 days, may be of importance in direct contamination of vegatation. Radioiodine is selectively concentrated in the thyroid gland, where excessive accumulations cause cancer and cell destruction. Injury to the gland may not be detected until long after the iodine has decayed."[1]

The Federal Radiation Council, in its Report #4, states that "In the special case where nearly all of the annual intake (of iodine 131) could come from exposure to abnormally high concentrations in a local area, resulting from a single nuclear explosion of low yield, the Council recognized that some small number of individual infants could conceivably receive doses 10 to 30 times the average for the area as a whole." The highest average dose to infant thyroids due primarily to one high excursion of levels in 1962 was 620 millirems in Salt Lake City, where most of the dose did

result from a single brief series of test explosions.[2] The highest individual dose, therefore, could have been 30 times the average, or 18.6 rems.

Thus, it has been recognized that iodine 131 represents a potentially important hazard from fallout. Until recently, considerations of this problem, with few exceptions, have been limited to iodine 131 exposures expected in the population as a whole during periods of active testing. This problem has been discussed in detail before the JCAE, and the St. Louis Committee for Nuclear Information has reported on it.[3,4] It has been recognized that rapid measurements of iodine 131 in milk provide a useful index of the radiation exposure to the thyroid expected in a child consuming the milk. While this type of information is therefore important in estimating the iodine 131 hazard from fallout it has certain limitations. Nearly all available measurements of iodine 131 in milk are based on large commercial supplies. These represent pooled milk from many widely scattered farms. Such measurements are, of course, valuable in estimating the iodine 131 intake of children who drink commercial milk of this type. However, the pooling process conceals variations in iodine 131 levels among separate regions and it is impossible to determine how much iodine 131 would be taken in by a child who consumes fresh milk directly from a cow or herd stationed in a particular local area. Nevertheless, the latter is the situation which governs milk consumption

of many rural children. Since much of the region surrounding the Nevada Test Site is occupied by farms and rather small towns, in which this type of local milk consumption must prevail, it becomes necessary to know the iodine 131 content of numerous separate small farm-size milk supplies in order to determine the iodine 131 intake of children living in this region.

Unfortunately appropriate measurements of iodine 131 in local milk supplies do not appear to have been made. For this reason direct estimates of the hazard to the thyroid are not possible, as they are in the case of many large-scale populations which consume commercial milk supplies. Iodine 131 measurements of commercial milk supplies for a number of cities have been available since 1957.

Because of the lack of such direct information on iodine 131 levels of milk consumed by children in the region of the Nevada Test Site, it becomes necessary to develop a method for estimating these values from other types of fallout measurements.

In what follows, we consider how this can be done.

2) Indirect estimation of iodine 131 levels from overall measurements of gamma and beta radiation

When nuclear fission occurs, a wide range of atomic products result. The physical processes which result in the appearance of the different products of nuclear fission have been studied extensively. From these studies,

it is known that particular radioisotopes, such as iodine 131, represent a relatively constant proportion of the total radioactive debris. Hence, if a measurement of the total amount of fallout is obtained it is possible to calculate the amount of iodine 131 produced. From this value one can estimate the amount of iodine 131 present in fallout by determining the "age" of the fallout, i.e. the time between its production in the nuclear explosion and its measurement, for like all radioisotopes iodine 131 decays with time. Thus, if one makes a measurement of the total gamma or beta radioactivity emitted by a sample of fallout, and can also determine its "age," it is possible to estimate the amount of iodine 131 present. The relevant calculations are presented in detail in the Appendix. During this interval some "fractionation" may possibly occur, i.e., as the fallout drifts along, some isotopes may become deposited out sooner than others. Not much is known about this process. In keeping with general practice in this field (see for example, Dunning, Hearings, Radiation Subcommittee, 1959, Biological and Environmental Effects of Nuclear War, p. 443), the possible effects of fractionation are not considered in our calculations.

Once an estimate of iodine 131 on the ground is available, it is possible quite readily to calculate how much of it will go into milk, and how much of the radioiodine in the milk will become concentrated in the thyroid of a child drinking one quart of milk per day (the standard usually used in fallout calculation).

20-519 O—63—pt. 2——10

This can be accomplished from a consideration of known cases of fallout and transmission from contamination on grass to milk and resultant thyroid iodine levels. Lapp[5] has made such a calculation based on the fallout incident at the Windscale pile No, 1, an experimental nuclear reactor, which caused the release of 20,000 curies of iodine 131 to the atmosphere. The iodine fell on farms in the area and then appeared in cows' milk in amounts as high as 100,000 micromicrocuries per liter. Though infants did not drink the milk because it was removed from the market, the thyroid radiation dose that would result from such concentrations can be calulculated on the basis of standard dosimetry procedures. The combined calculation indicates that $1 \mu c/M^2$ deposition of iodine 131 results in a dose of 5 rads to an infant thyroid gland. This is the basis for the lower of our two estimates. (See Appendix for details)

It should be noted that Lapp was not the first to make use of the Windscale experience. Gordon Dunning estimated in 1959 the thyroid dose due to raioiodine in fallout. His estimate indicates, "Based on Windscale experience, $1 \mu c I^{131}/M^2 \longrightarrow 0.1 \mu c I^{131}$/liter of milk. For one liter of this milk $\longrightarrow$ 2 rad dose to infant's thyroid. For continuous consumption of milk from cows grazing on pasture until I^{131} activity essentially zero $\longrightarrow$ 22-44 rad dose."[6] His calculation was for a wartime situation, but an atmospheric nuclear explosion creates and deposits radioactive fallout irrespective of the use to which it is put.

Dunning's estimate is somewhat higher than that derived in this paper from the Windscale evidence because he assumed that 100 per cent of deposited iodine 131 is retained on edible herbage, whereas we assume only 40 per cent. Higher yet is a figure based on experiments by R. J. Garner, who observed the transfer of iodine 131 from the diet of cows to their milk.[7] Based on Garner's data $1 \mu c I^{131}/M^2$ yields a 33 rad dose to the infant thyroid, for continuous ingestion.

Thus empirical evidence indicates a range for the infant thyroid dose due to a given deposition of iodine 131 on an area where milk cows graze. Using the steps described earlier, it is possible to estimate the thyroid dose on the basis of external beta and gamma intensities. For example, a gamma intensity of 30 milliroentgens/hour at Belmont, Nevada, 8 hours after an explosion on 28 May 1957 indicates an iodine deposition of 650 $\mu\mu c/cm^2$ and a possible resultant peak level in milk from cows eating grass in the area, of from 260,000 to 1,040,000 $\mu\mu c$/liter of milk. The dose to an infant's thyroid from continued ingestion of this milk would probably be between 32 and 214 rads. Or, using beta readings, the average beta count at Salt Lake City on May 7, 1952, for example, was 23,000,000 disintegrations per minute per square foot ($d/m/ft^2$). This would be expected to lead to infant thyroid doses of from 3 to 18 rads.

3) Estimates of Theoretically Possible Thyroid Doses Due to Short-Range Fallout From the Nevada Test Site

As shown above it is possible to calculate, from local measurements of gamma and beta radiation, what radiation exposure to a child's thyroid might theoretically result from a given deposit of fallout. Since the AEC has reported numerous measurements of gamma and beta radiation, together with the times of measurement, and their relation to a particular nuclear explosion (the time of which is also given), these data can be converted to estimates of possible iodine 131 exposures to the thyroid according to the procedures outlined above, and given in detail in the Appendix. Such calculations have been made for 189 different readings at various locations following 31 different nuclear test shots conducted at the Nevada Test Site during the period 1952-1958. The overall results are presented in Tables I-V. In each case, two estimates of the possible thyroid dose have been calculated, using the two different observations (Windscale and Garner) described above. The lower of the two estimates yields thyroid dosages which range from 0.6 rad to 555 rads. The higher of the two estimates yields thyroid dosages which range from 4 rads to 3260 rads. According to the higher estimate, of the separate locations, 69 received sufficient fallout to result in a possible dose of 100 rads or more to the thyroid. In 20 cases even the lower estimate yielded a thyroid dose over 100 rads. It is evident from this summary that the Nevada tests have produced instances of

Some Estimated Infant Thyroid Doses for 1953.

(Operation Upshot-Knothole). [8,9]

Table I

Hot Spot Location	γ Rate mr/hr	Time of Reading H + hrs	I-131 Density $\mu\mu c/cm^2$	I-131 in Fresh Milk $\mu\mu c/l$ based on: Windscale	Garner	Dose to infant Thyroid-Rads Wind-scale	Garner
SHOT ANNIE - 0520 PST -17 MARCH 1953 - 16.2 Kt. - 300' - TOWER							
St. George, Utah	20	8	504	202,000	806,000	25	167
Rockville, Utah	24	12	970	388,000	1,550,000	48	320
US 93, 30 mi N of Alamo, Nevada	110	7-1/3	2,380	952,000	3,810,000	119	785
US 91, 10 mi N of St. George, Utah	110	5	1,600	640,000	2,560,000	80	528
Nev 55, 22 mi N of US 91	260	2-2/3	1,800	720,000	2,980,000	90	594
SHOT NANCY - 0510 PST -24 MARCH 1953 - 24.4 Kt. -300' TOWER							
41 mi NW Crystal Springs, Nevada	140	5-1/2	2,030	812,000	3,250,000	102	670
Hwy 93, 59 mi S of Ely, Nevada	45	7-1/4	970	388,000	1,550,000	48	320
Adaven, Nevada	11	8	277	111,000	443,000	14	91
8 mi NW of Lincoln Mine, Nev.	85	9	2,460	984,000	3,940,000	123	812
32 mi SW of Lincoln Mine, Nev	32	58	7,250	2900,000	11,600,000	363	2,390
Sunnyside, Nevada	17	10-1/4	557	223,000	892,000	28	184
St. George, Utah	.3	12	12	4,800	19,200	.6	4
SHOT BADGER - 0435 PST - 18 APRIL 1953 - 23.0 Kt. - 300' - TOWER							
17 mi SW of Glendale Jct. on Hwy 91	38	31-2/3	4,480	1,790,000	7,170,000	224	1,480
Jct Hwy US 91 and Nev 40	35	28	3,680	1470,000	5,890,000	184	1,210
14.5 mi W of Jct Nev 12 & 40 on 40	38	27-1/3	3,850	1540,000	6,160,000	192	1,270

Table I (Cont'd)

Hot Spot Location	γ Rate mr/hr	Time of Reading H + hrs	I-131 Density $\mu\mu c/cm^2$	I-131 in Fresh Milk $\mu\mu c/l$ based on: Windscale	Garner	Dose to Infant Thyroid-Rads Wind-scale	Garner
SHOT SIMON - -25 APRIL 1953 - 42.7 Kt. - 300' - TOWER							
Mesquite, Nevada	30	10	485	194,000	776,000	24	160
Bunkerville, Nevada	100	10-1/3	3,280	1,310,000	5,250,000	164	1,080
24 mi W of Mesquite on US 91	110	27-1/2	11,100	4,440,000	17,800,000	555	3,660
20 mi N of Glendale Jct on US 93	80	29	8,840	3,540,000	14,200,000	442	2,920
Alamo, Nevada	1.8	10-2/3	61	24,400	97,600	3	20
Groom Mine, Nevada	0.2	13	8.8	3,520	14,100	.4	3
Riverside Cabins	300	10	984	394,000	1,570,000	49	325
St. George, Utah	.5	12	20.2	8,080	32,300	1	6
Santa Clara, Utah	5.0	32	600	240,000	960,000	30	200
SHOT HARRY - 0505 PDT - 19 MAY 1953 - 32.4 Kt. - 300' - TOWER							
Hwy 93, 32 mi N of Glendale, Nevada	18	33	2,270	908,000	3,630,000	113	750
St. George, Utah	16	36	2,220	888,000	3,550,000	111	735
Washington, Utah	28	13	1,240	496,000	1,980,000	62	409
Virgin, Utah	42	8	1,060	424,000	1,700,000	53	350
Hurricane, Utah	80	11-1/2	2,940	1,180,000	4,700,000	147	970
Kanab, Utah	15	28-2/3	1,570	628,000	2,510,000	79	520
Rockville, Utah	80	9	2,320	928,000	3,710,000	116	765
Orderville, Utah	14	32	1,685	674,000	2,700,000	84	555
Cedar City, Utah	18	12	730	292,000	1,170,000	36	240
Veyo, Utah	20	28-1/2	2,100	840,000	3,360,000	105	695

Table II
Some Estimated Infant Thyroid Doses for 1955 (Operation Teapot).[1,10]

Hot Spot Location	γ Rate mr/hr	Time of Reading H + hrs	I-131 Density $\mu\mu c/cm^2$	I-131 in Fresh Milk $\mu\mu c/l$ based on: Wind-scale	Garner	Dose to Infant Thyroid-Rads Wind-scale	Garner
SHOT WASP - 18 FEB. 1955 - 1.2 Kt. - 726' - AIR DROP							
Nev 85, 28 mi S of Pahrump	5.5	3.6	62	24,800	99,200	3	21
SHOT MOTH - 22 FEB. 1955 - 2.4 Kt. - 300' - TOWER							
Dry Lake, Nevada	6.0	6.3	109	43,600	174,000	5	36
US 93-91, 1 mi SW Dry Lake	29	6.4	525	210,000	840,000	26	173
SHOT TESLA - 1 MARCH 1955 - 6.8 Kt. - 300' - TOWER							
Santa Clara, Utah	6.0	11.3	220	88,000	352,000	11	73
St. George, Utah	4.0	10.2	131	52,400	210,000	7	43
Gunlock, Utah	0.3	10.9	11	4,400	17,600	.6	4
Ash Springs, Nevada	4.5	9.2	130	52,000	208,000	7	43
25 mi S of Alamo on US 93	55	5.2	800	320,000	1,280,000	40	264
SHOT TURK - 7 MARCH 1955 - 43.0 Kt. - 500' TOWER							
Current, Nevada	.98	29.4	108	43,200	173,000	5	36
Ely, Nevada	1.00	28.4	105	42,000	168,000	5	35
Warm Springs, Nevada	1.50	34.8	203	81,200	325,000	10	67
6 mi S Lockes on US 6	3.00	31.0	405	162,000	648,000	20	134
SHOT HORNET - 12 MARCH 1955 - 300' - TOWER							
Glendale, Nevada	14.0	7.7	353	141,000	565,000	18	116
Moapa, Nevada	10.0	6.5	216	86,400	346,000	11	71
Warm Springs Ranch	7.0	5.2	102	40,800	163,000	5	34
SHOT BEE - 22 MARCH 1955 - 8.1 Kt. - 500' - TOWER							
Las Vegas, Nevada	9.0	5.5	163	65,200	261,000	8	54
North Las Vegas, Nev.	13.0	5.1	189	75,600	302,000	9	62
US 93-95, 3 mi S of Henderson	18	5.1	261	104,000	418,000	13	86

Table II (Cont'd)

Hot Spot Location	γ Rate mr/hr	Time of Reading H + hrs	I-131 Density $\mu\mu c/cm^2$	I-131 in Fresh Milk $\mu\mu c/l$ based on: Windscale	Garner	Dose to Infant Thyroid-Rads Windscale	Garner
SHOT ESS - 23 MARCH 1955 - SUBSURFACE							
Lake Mead Base, Nev	1.5	4.0	16.8	6,720	26,900	.8	6
Glendale, Nevada	1.5	7.2	32.4	13,000	51,800	2	11
US 93, 38 mi S of Alamo	6.3	3.0	50.4	20,200	80,600	3	17
22 mi N Indian Springs, Nevada	140.0	5.3	2,030	812,000	3,250,000	102	670
SHOT APPLE I - 29 MARCH 1955 - 15.5 Kt. - 500' - TOWER							
Alamo, Nevada	160.0	2.8	1,280	512,000	2,050,000	64	422
Panaca, Nevada	2.5	5.9	45	18,000	72,000	2	15
Caliente, Nevada	9.0	4.9	131	52,400	210,000	7	43
Enterprise, Utah	9.5	6.8	206	82,400	330,000	10	68
Kanarraville, Utah	10.0	5.7	181	72,400	290,000	9	60
Newcastle, Utah	10.0	6.7	216	86,400	346,000	11	71
Hamilton Fort, Utah	6.0	5.7	109	43,600	174,000	5	36
SHOT MET - 9 APRIL 1955 - 300' - TOWER							
Buckhorn Ranch, Nev	140	2.6	1,120	448,000	1,790,000	56	370
Elgin, Nevada	200	5.1	2,900	1,160,000	4,640,000	145	957
Beryl, Utah	6.0	6.6	130	52,000	208,000	6	43
Zane, Utah	16.0	6.8	346	138,000	552,000	17	114
Lund, Utah	9.0	7.3	194	77,600	310,000	10	64
Beaver, Utah	3.5	25.3	315	126,000	504,000	16	104
Minersville, Utah	2.5	22.1	208	83,200	333,000	10	68

Table II (Cont'd)

Hot Spot Location	γ Rate mr/hr	Time of Reading H + hrs	I-131 Density μμc/cm²	I-131 in Fresh Milk μμc/l based on:		Dose to Infant Thyroid-Rads	
				Windscale	Garner	Wind-scale	Garner
SHOT APPLE II -5 MAY 1955 - 30.0 Kt. - 500' - TOWER							
Adaven, Nevada	18.0	4.2	202	80,800	323,000	10	67
Nyala, Nevada	30.0	5.8	544	218,000	872,000	27	180
Fallini Ranch, Nevada	13.0	5.0	189	75,100	302,000	9	62
Reed, Nevada	110.0	6.8	2,380	952,000	3,810,000	119	785
Lockes Ranch, Nevada	38.0	5.3	551	220,000	8,800,000	28	182
Currant, Nevada	8.0	6.5	173	69,200	277,000	9	57
Duckwater, Nevada	16.0	7.3	346	138,000	552,000	17	114
SHOT ZUCCHINI - 15 MAY 1955 - 500' - TOWER							
Warm Springs Ranch, Nevada	50.0	3.4	400	160,000	640,000	20	132
Moapa, Nevada	65.0	3.9	728	291,000	1,160,000	36	240
Crystal, Nevada	11.0	3.5	123	49,200	197,000	6	41
Logandale, Nevada	20.0	5.3	290	116,000	464,000	14	96
St. George, Utah	3.0	8.6	87	34,800	139,000	4	29
Cedar City, Utah	4.8	7.0	104	41,600	166,000	5	34
Washington, Utah	3.9	9.6	128	51,200	205,000	6	42
Parowan, Utah	5.5	11.7	223	89,200	357,000	11	74
Paragonah, Utah	4.6	11.8	186	74,400	298,000	9	62
Kanarraville, Utah	2.8	8.7	81	32,400	130,000	4	27

Table III

Some Estimated Infant Thyroid Doses for 1957.

(Operation Plumbob)[11,12,13]

Hot Spot Location	γ Rate mr/hr	Time of Reading H + hrs	I-131 Density $\mu\mu c/cm^2$	I-131 in Fresh Milk $\mu\mu c/l$ based on:		Dose to Infant Thyroid-Rads	
				Windscale	Garner	Windscale	Garner
SHOT BOLTZMAN - 28 MAY 1957 - 11.5 Kt. - 500' - TOWER							
Belmont, Nevada	30	7.7	650	260,000	1,040,000	32	214
Currant, Nevada	1.3	14.5	63	25,200	101,000	3	21
Fallon, Nevada	1.0	40	156	62,400	250,000	8	51
Millott, Nevada	2.5	35.7	335	134,000	536,000	17	110
Parmon's Ranch, Nev	22.0	10.7	716	286,000	1,140,000	36	236
Reveille Mill, Nev	80.0	10.7	2,620	1,050,000	4,200,000	131	865
Round Mt., Nevada	6.0	9.9	197	78,800	315,000	10	65
Stone Cabin Ranch	14	8.7	352	141,000	564,000	17	116
Stone House Ranch	45	9.7	1,300	520,000	2,080,000	65	430
SHOT WILSON - 18 JUNE 1957 - 10.3 Kt. - 500' - BALLOON							
Beatty, Nevada	2.0	7.2	43	17,200	68,800	2	13
SHOT PRISCILLA -24 JUNE 1957 - 36.6 Kt. - 700' - BALLOON							
Buckhorn Ranch, Nev	1.2	11	44	17,600	70,400	2	15
Carp, Nevada	4.5	10.7	148	59,200	237,000	7	49
Leith, Nevada	3.5	10.2	114	45,600	182,000	6	37
Anderson Jct, Utah	2.0	15.2	104	41,600	166,000	5	34
Gunlock, Utah	2.0	11.0	73.5	29,400	118,000	4	24
Leeds, Utah	2.0	15.0	105	42,000	168,000	5	35
Pintura, Utah	2.5	15.3	130	52,000	208,000	7	43
Veyo, Utah	8.0	10.1	262	105,000	420,000	13	86
New Harmony, Utah	.29	35.8	39	15,600	62,400	2	13

Table III (Cont'd)

Hot Spot Location	γ Rate mr/hr	Time of Reading H + hrs	I-131 Density μμc/cm^2	I-131 in Fresh Milk μμc/l based on: Windscale	Garner	Dose to Infant Thyroid-Rads Wind-scale	Garner
SHOT DIABLO - 15 JULY 1957 - 17 Kt. - 500' - TOWER							
Bardoli Ranch, Nev	2.5	12.3	101	40,400	162,000	5	33
Belen Ranch Adaven, Nevada	8.5	11.5	286	114,000	456,000	14	94
Ely, Nevada	3.7	14.4	179	71,600	286,000	9	59
Geyser Ranch, Nev	7.0	16.7	416	166,000	664,000	21	137
Groom Mine, Nevada	75	8.2	1,890	756,000	3,020,000	94	625
Lincoln Mine, Nev	52	8.0	1,310	524,000	2,100,000	65	430
Lund, Nevada	4.4	13.0	1,940	776,000	3,100,000	97	640
Preston, Nevada	4.2	13.2	1,850	740,000	2,960,000	93	610
South Paw Mine, Nev	12.5	11.3	459	184,000	736,000	23	150
Sunnyside, Nevada	8.7	11.2	320	128,000	512,000	16	105
Uhalde Ranch, Nev	11.0	8.4	277	111,000	444,000	14	100
Walch Pine Creek Ranch, Nevada	4.5	14.5	218	87,200	349,000	11	72
Whipple Ranch	1.5	12.5	60	24,000	96,000	3	20
SHOT KEPLER - 24 JULY 1957 - 10.3 Kt. - 500' - TOWER							
Basalt, Nevada	1.5	13.0	66	26,400	106,000	3	22
Coaldale, Nevada	9.5	13.0	420	168,000	672,000	21	138
Goldpoint, Nevada	6.5	9.2	188	75,200	301,000	9	62
Silverpeak, Nevada	7.5	11.9	304	122,000	488,000	15	100

Table III (Cont'd)

Hot Spot Location	γ Rate mr/hr	Time of Reading H +hrs	I-131 Density μμc/cm^2	I-131 in Fresh Milk μμc/l based on:		Dose to Infant Thyroid-Rads	
				Windscale	Garner	Wind-scale	Garner
SHOT OWENS - 25 JULY 1957 - 9.7 Kt. - 500' - BALLOON							
Bardoli Ranch, Nev	1.7	7.1	33	13,200	52,800	2	11
Currant, Nevada	5.5	5.8	80	32,000	128,000	4	26
El Dorado, Nevada	1.4	9.9	46	18,400	73,600	2	15
Eureka, Nevada	1.3	8.0	33	13,200	52,800	2	11
Fallini Ranch, Nev	1.8	5.3	26	10,400	41,600	1	9
Nyala, Nevada	2.5	6.7	45	18,000	72,000	2	15
SHOT SHASTA - 18 AUGUST 1957 - 16.5 Kt. - 500' TOWER							
Bardoli Ranch, Nev	4.8	10.3	157	62,800	251,000	8	52
Currant Nevada	3.5	8.7	88	35,200	141,000	4	29
Eureka, Nevada	13.0	10.5	430	172,000	688,000	21	142
Fallini Ranch, Nev	33.0	6.9	710	284,000	1,140,000	35	235
Lockes, Nevada	7.0	8.1	176	70,400	282,000	9	58
Lund, Nevada	2.5	10.6	82	32,800	131,000	4	27
Nyala, Nevada	6.0	8.7	151	60,400	242,000	8	50
Preston, Nevada	3.5	10.2	115	46,000	184,000	6	38
Reveille Mill, Nev	20	6.0	362	145,000	580,000	18	120

Table III (Cont'd)

Hot Spot Location	γ Rate mr/hr	Time of Reading H + hrs	I-131 Density μμc/cm^2	I-131 in Fresh Milk μμc/l based on:		Dose to Infant Thyroid- Rads	
				Windscale	Garner	Wind-scale	Garner
SHOT SMOKY - 31 AUGUST 1957 - 44.0 Kt. - 700' - TOWER							
Butler Ranch, Nev	360	3.8	2,880	1,150,000	4,600,000	144	950
Glendale Jct, Nev	2.0	12.4	81	32,400	130,000	4	27
Mesquite, Nevada	2.0	13.6	88	35,200	141,000	4	29
Rox, Nevada	8.8	8.5	222	88,800	355,000	11	73
Anderson Jct, Nev	11.0	10.7	360	144,000	576,000	18	119
Cedar City, Utah	3.0	11.9	110	44,000	176,000	5	36
Central, Utah	6.0	10.9	98	39,200	157,000	5	32
Gunlock, Utah	7.0	9.7	203	81,200	325,000	10	67
Hurricane, Utah	2.5	12.2	101	40,400	162,000	5	33
Leeds, Utah	17	9.5	494	198,000	790,000	25	163
Rockville, Utah	2.0	12.8	81	32,400	130,000	4	27
St. George, Utah	14.0	12.5	467	187,000	747,000	24	154
Veyo, Utah	15	10.0	491	196,000	786,000	25	162
Virgin, Utah	2.0	12.6	81	32,400	130,000	4	27
Washington, Utah	4.0	11.6	147	58,800	235,000	7	48
Rock Springs, Wyo	5.0	12	203	81,200	325,000	10	67
SHOT GALILEO - 2 SEPTEMBER 1957 -11.4 Kt. - 500' - TOWER							
A & B Mine, Nevada	3.0	13.4	132	52,800	211,000	6	43
Fallini Ranch, Nev	0.8	14.7	39	15,600	62,400	2	13
Parmon Ranch, Nev	0.9	14.0	40	16,000	64,000	2	13
Reveille Mill, Nev	3.5	11.7	128	51,200	205,000	6	42
Stone Cabin Ranch	2.3	10.8	75	30,000	120,000	4	25

Table IV

Some Estimated Infant Thyroid Doses for 1958 (Operation Hardtack-II)[14]

Hot Spot Location	γ Rate mr/hr	Time of Reading H + hrs	I-131 Density $\mu\mu c/cm^2$	I-131 in Fresh Milk $\mu\mu c/l$ based on:		Dose to Infant Thyroid-Rads	
				Windscale	Garner	Wind-scale	Garner
SHOT QUAY - 10 OCTOBER 1958 - 79 Kt. - 100' - TOWER							
Beatty, Nevada	1.4	7.7	30	12,000	48,000	2	10
Hwy 58 10 mi N of Beatty, Nevada	2.5	4.92	36	14,400	57,600	2	12
SHOT LEA - 13 OCTOBER 1958 - 1500' - BALLOON							
8 mi. W of Cliff Spring, Nevada	1.5	9.3	43.5	17,400	69,600	2	14
8 mi. W of Reed on old hwy 25	3.3	9.3	96	38,400	154,000	5	32
SHOT RIO ARRIBA - 18 OCTOBER 1958 - 90 Kt. - 70' - TOWER							
Below Ranch, Nev	1.8	7.5	39	15,600	62,400	2	13
Casey Ranch, Nev	1.4	8.0	35	14,000	56,000	2	12
Sharp Ranch, Nev	1.5	8.3	38	15,200	60,800	2	13
Uhalde Ranch, Nev	1.7	7.3	37	14,800	59,200	2	12
Walch Ranch, Nev	1.6	6.6	29	11,600	46,400	1	10

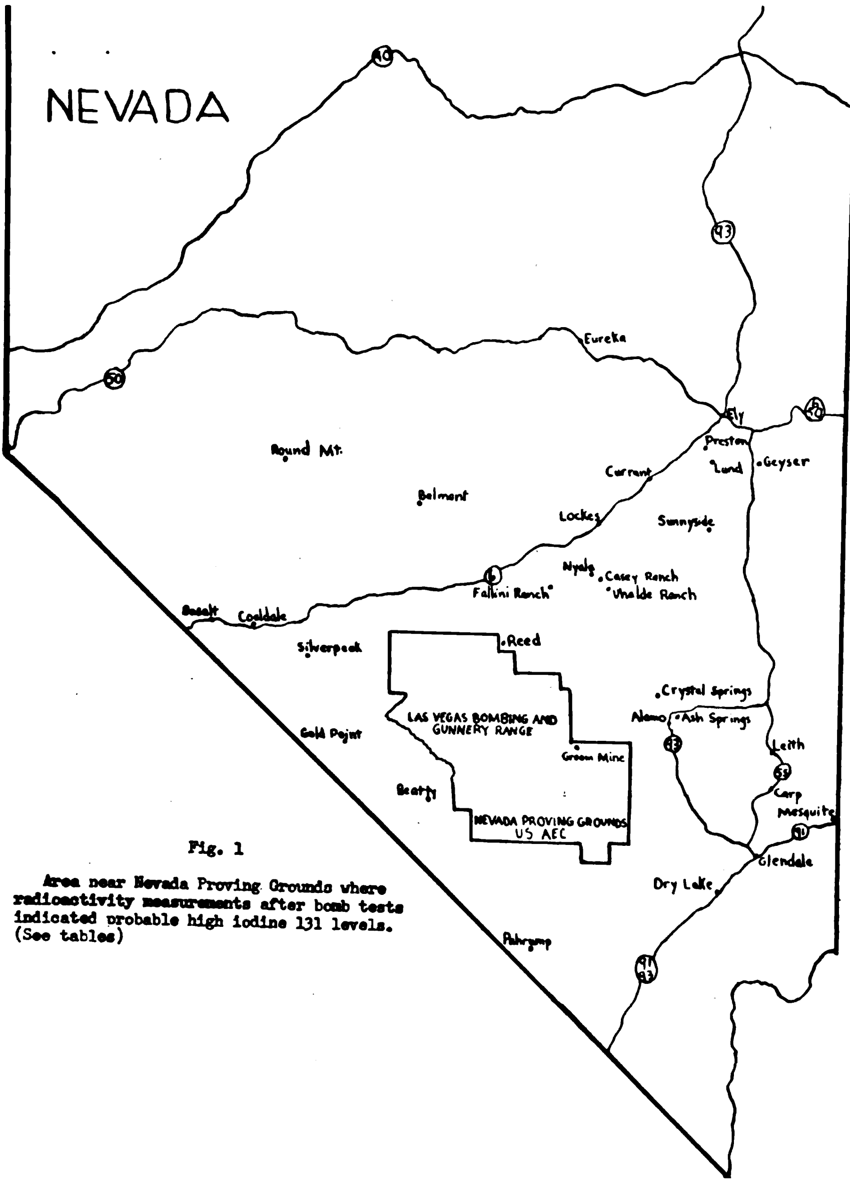


Fig. 1

Area near Nevada Proving Grounds where radioactivity measurements after bomb tests indicated probable high iodine 131 levels. (See tables)

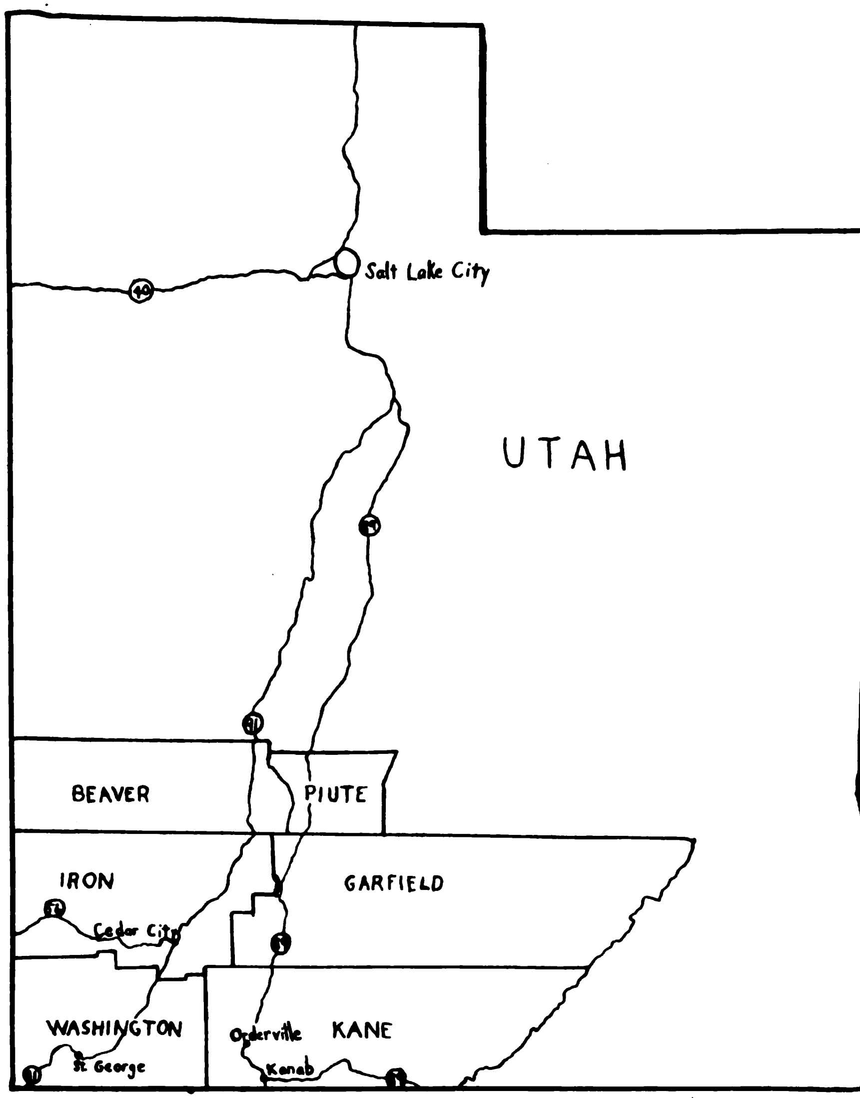


Fig. 2

Area in Utah where radioactivity measurements after bomb tests indicated probable high iodine 131 levels. (See tables)

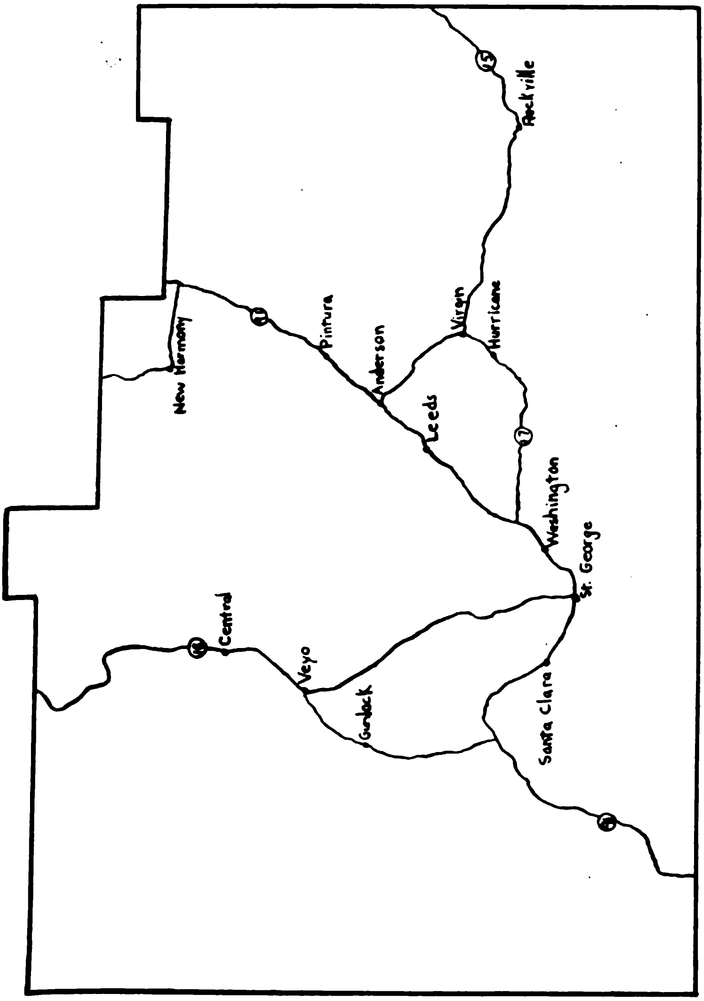


Fig. 3

Washington County, Utah with points at which repeated high radioactivity measurements indicated probable high iodine 131 levels for most of the county. (See tables)

20-519 O—63—pt. 2——11

fallout sufficiently intense to result in medically significant radiation exposure to childrens' thyroids in an appreciable number of instances.

Some locations in the Nevada region have received such possible dosages on repeated occasions.

Currant, Nevada, for instance, a town of about 75 people located about 80 miles north of the test site, received significant doses on March 7, 1955; May 5, 1955; May 28, 1957; July 15, 1957; July 25, 1957; and August 18, 1957. Infant thyroid doses would all be greater than 2.5 rads, and in 4 cases out of the 5, could have exceeded 25 rads. Another example is Lockes, Nevada which received three significant doses, all of which were 9 rads or more by the lower estimate. By the higher estimate, the doses on two occasions may have exceeded 100 rads.

Washington county, Utah is one of the most heavily populated of the areas to receive heavy fallout depositions. It is an area in which, on at least one occasion (May 19, 1953), citizens in several communities were asked to stay indoors for several hours after a test shot. Fallout on that date blanketed the entire county. Infant thyroid doses due to contaminated milk might have reached from 150 to 950 rads in Hurricane, Utah, and it is very likely that the <u>minimum</u> dose for infants in most of the county due to milk from cows fed fresh pasturage was about 50 rads.

The largest town in Washington County, St. George, (population 5,000) received possible maximum doses of

Table V

Some Estimated Infant Thyroid Doses in Areas Distant from the Nevada Test Site, for 1952 (Operation Tumbler-Snapper) and 1953 (Operation Upshot-Knothole)[15,16]

Hot Spot Location	Gross β d/m ft^2 x 10^{-6}	Average Time of Reading H + hrs	I-131 Density $\mu\mu c/cm^2$	I-131 in Fresh Milk $\mu\mu c/l$ based on: Windscale	Garner	Dose to Infant Thyroid-Rads Windscale	Garner
SHOT EASY - 7 MAY 1952 - 12 Kt. - 300' - TOWER							
Salt Lake City, Utah	23	12	54.1	21,600	86,400	3	18
SHOT GEORGE - 1 JUNE 1952 - 14.6 Kt. - 300' - TOWER							
Pocatello, Idaho	4.2	12	9.9	3,960	15,800	.5	3
Norfolk, Nebraska	.78	60	11.3	4,520	18,100	.6	4
Terre Haute, Indiana	1.38	36	11.2	4,480	17,900	.6	4
Grand Rapids, Mich	1.2	36	9.8	3,920	15,700	.5	3
SHOT HOW -5 JUNE 1952 - 13.9 Kt. - 300' - TOWER							
Boise, Idaho	17.7	12	41.6	16,600	66,400	2	14
Great Falls, Montana	10.8	12	25.2	10,100	40,400	1	8

Table V (Cont'd)

Hot Spot Location	Gross β d/m/ft² x 10⁻⁶	Average Time of Reading H + Hrs	I-131 Density μμc/cm²	I-131 in Fresh Milk μμc/l based on: Windscale	Garner	Dose to Infant Thyroid -Rads Windscale	Garner
SHOT ANNIE - 17 MARCH 1953- 16.2 Kt. - 300' - TOWER							
Knoxville, Tennessee	1.9	36	15.5	6,200	24,800	.8	5
SHOT NANCY - 24 MARCH 1953 - 24.4 Kt. - 300' - TOWER							
Salt Lake City, Utah	15.0	12	35.3	14,100	56,400	2	12
Ely, Nevada	6.3	12	14.8	5,920	23,700	.7	5
Rapid City, S. D.	2.04	36	16.6	6,640	26,600	.8	5
SHOT DIXIE -6 APRIL 1953 - 10.9 Kt. - 300' - TOWER							
Boston, Mass.	5.1	36	41.6	16,600	66,400	2	14
SHOT BADGER - 18 APRIL 1953 - 23 Kt. - 300' - TOWER							
Port Arthur, Texas	1.5	36	12.2	4,880	19,500	.6	4
SHOT SIMON - 25 APRIL 1953-42.7 Kt. - 300' - TOWER							
Grand Junction, Col.	2.9	36	23.6	9,440	37,800	1	8
Roswell, N.M.	13.0	36	106	42,400	170,000	5	35
Albuquerque, N. M.	2.4	36	19.6	7,840	31,300	1	6
Albany, New York	16	36	131	52,400	209,000	7	43
SHOT HARRY - 19 MAY 1953 - 32.4 Kt. - 300' - TOWER							
Grand Junction, Col	11	12	25.9	10,300	41,200	1	9
Des Moines, Iowa	1.5	36	12.2	4,880	19,500	.6	4
Albuquerque, N. M.	7.8	12	18.4	7,360	29,400	1	6

25-165 rads on March 17, 1953; 110-735 rads on May 19, 1953; 7-42 rads on March 1, 1955; 4-29 rads on May 15, 1955; and 28-154 rads on August 31, 1957.

These doses are representative of the whole of Washington county.

The August 31, 1957, value was due to shot "Smoky" of Operation Plumbob. Fallout from this explosion resulted in measurements indicating significant infant thyroid doses over an 8000 square mile area outside the Test Site, of which Washington county comprised 2500 square miles. High levels were reported as far away as Rock Springs, Wyoming, 700 miles from the Test Site.

Cases of relatively high thyroid doses in locations distant from the Nevada Test Site appear to be fewer than near the Site, although this may be due in part to the fact that monitoring outside the test area is even less extensive than for the region within a 200 mile radius. One distant case was that in Troy, New York, on April 26, 1953. Contamination of milk was not measured at that time but Ralph Lapp estimates that iodine 131 in milk might have reached 100,000 $\mu\mu$c per liter. As a result, infants may have received doses to the thyroid as high as 30 rads.

During 1952 and 1953, one to ten rad doses or more to infant thyroids may have occurred in areas near Salt Lake City on May 7, 1952, and again on March 24, 1953; at Boise, Idaho and Great Falls, Montana on June 5, 1952; Boston, Massachusetts

on April 17, 1953; Grand Junction, Colorado, Roswell, and Albuquerque, New Mexico (as well as Troy and Albany, New York) on April 26, 1953, and Grand Junction again on May 19, 1953.

4) Were the theoretically possible doses actually received by childrens' thyroids as a result of fallout from the Nevada Test Site?

It has already been pointed out that the above estimates are theoretical, in that they show what thyroid radiation dosages might result, providing that the iodine 131 in the deposited fallout actually entered the food chain and was ingested by children locally from locally-produced milk.

What is the likelihood that such doses did actually occur? Two conditions must have been met: that there were milk cows grazing in the contaminated pastures, and that children drank the milk. Monitoring reports have rarely supplied information of any detail on these questions (no detailed information is available for the tests held in 1952, 1955 and 1958; for 1953 testing, one survey to check for grazing animals in areas of high fallout was reported; and for 1957 testing, and again for 1961 and 1962, milk monitoring data of limited value are available). Census reports, however, indicate that there were 4438 milk cows on the farms and ranches in Lincoln, Nye, Clark, Elko and White Pine counties, in Nevada (the areas closest to the

Table VI
MILK COWS IN SEVERAL COUNTIES NEAR THE NEVADA TEST SITE

		NUMBER OF COWS					
		1950		1954		1959	
County	State	Farms Reporting	Milk Cows	Farms Reporting	Milk Cows	Farms Reporting	Milk Cows
Washington	Utah	556	1898	469	2127	319	1660
Iron	"	324	1085	259	980	200	799
Clark	Nev.	157	1486	108	1565	83	2096
Elko	"	251	1185	213	791	161	493
Lincoln	"	103	556	78	444	60	459
Nye	"	87	330	76	340	64	318
White Pine	"	111	881	86	642	83	554

		SIZE OF HERDS, 1959 Number of Cows in Herd					
		1	2-9	10-19	20-29	30-49	50+
		Number of Herds					
Washington	Utah	148	136	10	11	11	3
Iron	"	81	103	5	6	4	1
Clark	Nev.	27	32	1	3	7	13
Elko	"	37	121	3	none	none	none
Lincoln	"	18	32	3	3	2	2
Nye	"	29	33	1	none	none	1
White Pine	"	21	52	1	1	6	2

test site) in 1950. These same counties had 3782 milk cows in 1954, 3920 in 1959. Only one county, Nye, consistently reported fewer than 500. A more detailed report for 1959 indicated that out of 451 farms reporting in these counties, 402 of these had between one and nine; and 49 had herds of 10 or more.

Washington county, Utah (which has received repeated high fallout, as noted earlier) had 1898 milk cows in 1950, 2127 in 1954 and 1660 in 1959. In 1959 219 farms reporting had one to nine milk cows and the remaining 100 had 10 or more.

The one detailed survey in 1953 reported 200 cows at a point 75 miles northeast of the test site on March 24, 1953 and seven herds of milk cows near St. George, Utah on May 19, 1953. The cows near St. George reportedly received t total external doses from 3 to 6 rads on that date, (the date of shot "Harry.")[8] This corresponds to contamination on their pasture which may have caused infant thyroid doses from 100 to 1000 rads.

Were there infants and children in the area to drink this milk? 1960 census figures (these figures vary little from year to year) indicate about 19,000 children under 5

Table VII
POPULATION STATISTICS FOR SELECTED COUNTIES NEAR THE NEVADA TEST SITE

County	State	Total Pop.	Per cent residence rural farm	Per cent under 5 years old	Live Births
			1950		
Washington	Utah	9,836	23	data for	332
Iron	"	9,642	10	this age	306
Clark	Nev.	48,289	24.2	group	1,247
Elko	"	11,654	17.6	not	254
Lincoln	"	3,837	10.6	available	91
Nye	"	3,101	16	for 1950	53
White Pine	"	9,424	8.6		232
			1960		
Washington	Utah	10,271	5.2	12.8	230
Iron	"	10,795	3.9	13	274
Clark	Nev.	127,016	1	12.4	3,554
Elko	"	12,011	13.7	11.3	292
Lincoln	"	2,431	6.0	11.9	56
Nye	"	4,374	10.1	9.5	64
White Pine	"	9,808	4.3	12	208

years of age, and 4174 live births per year in the counties of interest in Nevada. In Washington county, Utah, there were 1315 children under 5 in 1960, 230 live births in 1960 and 332 live births in 1950. This indicates that there were approximately 250 to 300 children of 6 to 18 months in the county at any given time.

Individual children on any of a large number of ranches could have received high thyroid radiation doses (such as, for instance, the 21 to 137 rads possible at the Geyser Ranch in Nevada on July 15, 1957). There are repeated cases in which we know it is quite likely that a considerable number were exposed. The entire Washington county was blanketed with fallout levels that could cause 5-100 rad or higher doses on at least 7 different occasions.

Not only was fresh milk on farms probably affected, but also pasteurized milk, for much of the milk delivered in the county is not mixed with milk from other areas. St. George has one local dairy, the Whitehead Dairy, which collects milk only in Washington County, in the immediate vicinity of St. George, and distributes it locally. The Arden Meadowgold Dairy collects its milk in nearby Iron, Piute and Beaver counties. These dairies have been in business throughout the period under consideration with the same collection and distribution pattern.[19]

Pasteurized milk from these dairies would be expected to have iodine levels lower by a factor of .85 than the

fresh milk from the area. This is due to the decay in radioactivity taking place in two days--the time it takes to collect, process and distribute th milk.

(Other dairies active in Washington County are the Anderson Dairy, which ships milk out to Las Vegas, where it is presumably pooled with other milk, and the Highland Dairy, which has come in more recently, distributing milk from northern Utah.)

The chain, therefore, from nuclear explosion through fallout, pasture, cow and milk to children has been completed in many of these areas and for a considerable number of children. What biological effect would be expected from these exposures?

5) <u>The biological significance of these levels</u>

It is now well known that radioactive iodine presents a special hazard to infants for the following reasons:

> 1. Milk is the largest human dietary source of iodine 131 and children generally drink more milk than adults.
>
> 2. For the same quantity of iodine in the food eaten, the cells of the thyroid of an infant receive 10 to 15 times the dose received by the cells of an adult thyroid. The infant thyroid is much smaller, generally weighing about 2 grams, whereas the adult thyroid weighs about 20 grams. In the infant a given quantity of radiation is spread over a much smaller mass, and each gram receives a greater amount of radiation.
>
> 3. The infant's thyroid may be more sensitive than the adult's to cancer induction by radiation. Thyroid cancer was observed in children after a single exposure to radiation of 150 rem.[4]

The Federal Radiation Council, in its Report No. 2 discusses the carcinogenic effect of radiation on the thyroids of children, drawing upon the evidence of significantly higher incidence of carcinoma in children who had been exposed to x-irradiation in the neck region, than in control groups not so exposed.

The smallest dose capable of inducing cancer is not known, but it is generally assumed that the frequency of induced cancer may be proportional to dose, down to very low levels of exposure. On the assumption of no threshold, Beach and Dolphin of the United Kingdom Atomic Energy Authority estimate that if one million infants were exposed to <u>one</u> rad of thyroid radiation, 35 would be expected to develop thyroid cancer.

The AEC's permissible <u>external</u> effective biological dose of 3.9 r could result in an <u>internal</u> thyroid dose of 175 to 1200 rads, and actual exposures, as we have shown, may have ranged from well below to well above this dosage.

6) <u>Underground tests</u>

Significant radiation levels from continental testing have not been confined to surface and atmospheric shots. Venting of subsurface shots has been reported for at least seven cases: March 23, 1955 (shot ESS, of Operation Teapot); September 15, 1961; December 10, 1961 (Project Gnome); March 5, 1962; April 14, 1962; May 19, 1962; June 13, 1962 (the Des Moines shot) and July 6, 1962 (the Sedan shot, 100 kiloton shot 635 feet underground).[1,20,21] The Des Moines shot resulted

in a peak of 1240 μμc/liter in milk of Spokane, Washington on June 21. According to a Weather Bureau study, "The initial appearance phase (July 8-12) for iodine 131 in milk (in Salt Lake City) would appear to have been due to the July 6 (Sedan) test."[21]

The Gnome shot in New Mexico may have resulted in thyroid doses in the range from 7 to 55 rads in the immediate vicinity of Carlsbad.

7) <u>Limitations of these estimates</u>

Any objective appraisal of the estimates made here must take into account their limitations.

The main problem is a general lack of useful data. In most cases, detailed milk data was not reported, and when it was, the information was not in usable form.

Table VIII

Some estimated infant thyroid doses for Project Gnome (December 10, 1961). Data are from AEC report number PNE - 132 F

Hot Spot Location	γ Rate mr/hr	Time of Reading H +hrs	I-131 Density $\mu\mu c/cm^2$	I-131 in Fresh Milk μμc/l based on:		Dose to Infant Thyroid-Rads	
				Windscale	Garner	Wind-scale	Garner
Roswell, New Mexico	.3	10.17	9.84	3,940	15,700	.5	3
7.4 mi W Jct 31 & 285 on 31	?.0	13.77	308	124,000	495,000	15	102
3.6 mi E of Carlsbad on 62/180	4.0	10.25	131	52,000	210,000	7	43
40 mi E Bataam Bridge on 62/180	5.0	9.75	145	57,000	232,000	7	48

In 1953, some observations of dairy herds were made, and external doses received by them were estimated, but actual data on fresh milk given just after the exposures are not available. In 1957, during Operation Plumbob, milk was tested, but only for gross beta radiation and for strontium 90. The gross beta values do not provide a basis, in this case, for inferring iodine levels, and while calculations can be made from strontium levels, they do not carry the same certainty as actual iodine figures.

Detailed milk monitoring figures were not reported for the 1958 test series, Operation Hardtack II. The two tests for which such monitoring was reported were Project Gnome, December 10, 1961, at Carlsbad, New Mexico and the Des Moines shot, June 13, 1962. However, all iodine measurements for Gnome were made in milk collected either before the test, or at least one month after the test, when any high levels that might have occurred had already dissipated.[22]

For the Des Moines test milk was again monitored either too early (June 13, the day of the test) or too late.[23] Concentrations of 600 and 500 micromicrocuries per liter were found at two locations on June 20 and 21, but the actual peaks at those locations would have come about June 15-17, two to four days after the explosion.

More adequate data either have not been taken, or have not been made available to the public. (A report by the

AEC, "Safety at the Nevada Test Site," 1963 asserts "All of the essential data from these monitoring programs have been reported in the open literature."[24])

For areas distant from the Nevada Test Site, there are no milk data for the period before 1957, and data taken after that time have usually represented an area-wide, monthly average, so that detailed variations are obscured.

The limitation on the fallout monitoring program is clear from its budget. As stated in the 1963 Fallout hearings, Phase I, offsite monitoring costs run about $3/4 million per year.

At the 1957 hearings on fallout, the AEC stated, officially,

> These two isotopes - radio strontium and radioiodine - constitute the principle internal hazards from the radioactives produced by the detonation of atomic weapons, both fission and thermonuclear. The Atomic Energy Commission has been engaged for three years in a broad study of the radioactive forms of these isotopes and conducts year-round monitoring of these radioactivities in many locations. Any accumulation of these materials can be detected with great sensitivity so that ample warning of potential hazard could be given long before any actual danger occurred from test detonations. The amounts of radiostrontium and radioiodine which have fallen outside the areas near the test sites as a result of all atomic tests up to now are insignificant compared to concentrations that would be considered hazardous to health.

and

> The hazard has been successfully confined to the controlled area of the Test Site.

In the light of the present analysis, these statements are an incorrect estimate of the hazard to the local population from fallout in the Nevada Test Site region.

REFERENCES

1. "The Nature of Radioactive Fallout and its Effects on Man," Hearings before a subcommittee of the Joint Committee on Atomic Energy, May 27-June 3, 1957.

2. Federal Radiation Council. Report No. 4. May, 1963.

3. Pate, Brian D. "Short-Lived Radioactive Debris from Nuclear Weapons Tests," Nuclear Information, Jan., 1962.

4. Wurtz, Robert H. "The Iodine Story," Nuclear Information, Sept., 1962.

5. Lapp, Ralph, "Nevada Test Fallout and Radioiodine in Milk," Science, 141:640,1963.

6. "Biological and Environmental Effects of Nuclear War," Hearings before a subcommittee of the Joint Committee on Atomic Energy, June 22-26, 1959.

7. Garner, R. J. "An Assessment of the Quantities of Fission Products Likely to be Found in Milk in the Event of Aerial Contamination of Agricultural Land," Nature, 186:1963, June 25, 1960.

8. Collison, Tom D. "Report to the Test Director: Radiological Safety Operation." June, 1953. AEC report no. WT 817

9. Collison, Tom D. "Report to the Test Director: Radiological Safety Operation." March-June, 1953. AEC report no. WT 702.

10. LeVine, H. D., and R. T. Graveson. "Operation Teapot, Measurements of Off-site Fallout by Automatic Monitoring Stations." June 26, 1957. AEC report no. WT 1186.

11. Placak, O. R., et al. "Operation Plumbob Off-site Radiological Safety Report." 1957. AEC report no. OTO-57-3.

12. Larson, K. H., et al. "Summary Statement of Findings Related to the Distribution, Characteristics and Biological Availability of Fallout Debris Originating from Testing." 1960. AEC report no. UCLA 438.

13. Sigoloff, S. C., and H.M. Borella. "Operation Plumbob , Remote Radiological

Monitoring.", May, 1959, AEC report no WT 1509.

14.Placak, O.R. et al. "Operation Hardtack Phase II, Off-site Radiological Report, Nevada Test Site, 1958," Aug., 1959. AEC report no. OTO-58-6.

15.List, R.J. "Radioactive Debris from Operation Tumbler and Snapper. Observations beyond 200 miles from the Test Site. Part II" 1953. AEC report no. NYO 4512.

16.List, R.J. "The Transport of Atomic Debris from Operation Upshot-Knothole." June 25, 1954. AEC report no. NYO 4602.

17.Census of Agriculture, 1954 and 1959.

18.U.S. Bureau of Census, City and County Data Book, A Statistical Abstract Supplement. Editions for 1952 and 1962.

19.Personal communication from Whitehead Dairy, St. George, Utah.

20.U.S. Public Health Service, Radiological Health Data, July, 1962, p. ii.

21.U.S. Public Health Service, Radiological Health Data, 3:510 (Dec., 1962).

22.Placak, O.R. "Project Gnome, Carlsbad, New Mexico, Off-site Radiological Safety Report, 1961," May 22, 1962. AEC report no. PNE-132-F.

23.U.S. Public Health Service, Radiological Health Data, 3:402 (Oct., 1962).

24."Fallout, Radiation Standards, and Countermeasures," Hearings before a subcommittee of the Joint Committee on Atomic Energy, June 3-6, 1963, Part One.

Committee for Nuclear Information

The Greater St. Louis Citizens' Committee for Nuclear Information, founded in 1958, is the pioneer citizens' group in the field of nuclear education. CNI's program, a joint effort of scientists and laymen, is dedicated to making the known facts about nuclear energy and its effects better and more widely known. To do this, it assembles and studies available information on various nuclear problems, and presents the facts to the public, to scientists, and to the press.

CNI does not stand for or against particular policies. It presents the known facts for people to use in deciding where they stand on the moral and political questions of the nuclear age.

CNI publishes Nuclear Information, with a national circulation and provides the St. Louis area with a speakers bureau and scientific seminars. It also sponsors the Baby Tooth Survey, a ten-year scientific program to collect baby teeth as a way of monitoring the amount of strontium 90 from fallout absorbed by St. Louis children.

In the fall of 1961 and the summer of 1962, CNI called attention to the particular problems connected with iodine 131 in fallout, and the availability of simple countermeasures. Testimony has twice been presented to the Subcommittee on Research Development and Radiation of the Joint Committee on Atomic Energy (pp. 616-26 of the 1962 Hearings and pp. 471-3 of the 1963 Hearings).

20-519 O—63—pt. 2——12

Biographical Sketch

Eric Reiss, M.D.
Chairman, Technical Division
Committee for Nuclear Information

Eric Reiss was born in Vienna, Austria, 1924. B.S. Randolph-Macon College, 1943. M.D. Medical College of Virginia, 1948. Medical House Officer, Philadelphia General Hospital, 1948-50. Assistant Resident in Medicine, Barnes Hospital, St. Louis, 1954-1955. American Cancer Society Scholar in Medicine, Washington University School of Medicine, St. Louis, 1955-1960.

Captain and Major, U.S. Army Medical Department, Surgical Research Unit, Brooke Army Medical Center, 1950-1954; Chief, Clinical Division, 1953-1954.

Instructor in Medicine, 1956-1958; Assistant Professor of Medicine and Preventive Medicine, 1958-1962; Associate Professor of Medicine since 1962; Director, Irene Walter Johnson Institute of Rehabilitation, 1958- ; all at Washington University School of Medicine.

American Society for Clinical Investigation, Endocrine Society, Central Society for Clinical Research, Society for Experimental Biology and Medicine, A.A.A.S., American Medical Association; Sigma Xi, Alpha Omega Alpha, Phi Beta Kappa.

Appendix

I. The Problem

The purpose of this report is to develop a method of estimating the concentration of iodine 131 in fresh milk, and the possible thyroid dose, resulting from nuclear weapons testing in Nevada. Very few measurements of actual iodine 131 concentrations in fresh milk have been made, so that it is necessary to estimate these levels by indirect methods.

Several methods have been suggested previously in the literature. Dunning[1] and Lapp[2] both suggest a procedure based on the results of the Windscale accident in England.

Their procedure, similar to the one advanced in this report, is to estimate the amount of iodine 131 that would be found in fresh milk, given the iodine 131 deposition density on the grazing area.

Pendleton[3] takes a different approach. Basing his calculations on the data resulting from the Salt Lake City incident of July, 1962, he determines an empirical correlation between the gross beta concentration of fission products in air, and the iodine 131 levels in fresh milk.

The method to be developed here consists of three major steps:

Step 1: Estimate the iodine 131 deposition density from one of two directly observable phenomena: the external gamma dose rate, or gross beta activity on gummed film.

Step 2: Using the result of step 1, make two independent estimates of the iodine 131 level in fresh milk resulting from the grazing of cows on the contaminated pasture.

Step 3: From these estimates of iodine 131 in milk, calculate the expected dose to the infant thyroid from the consumption of one liter of contaminated milk per day.

Unfortunately, there exist no known data for checking the accuracy of the estimating procedure other than the Windscale results upon which it is based. The Milk Surveillance Network is designed to monitor pasteurized milk, so that the results of their measurements represent a composite of several milk sheds averaged, usually over an extended time. The effect of localized hot spots, particularly those occurring on farms and ranches near the Nevada Test Site, is therefore undetectable from analysis of their measurements.

II. Estimating Area Deposition of Iodine 131

A. External Three Foot Gamma

The gamma dose rate measured with portable radiation counters represents the open field dose rate in a particular area due to the total quantity of fission products deposited in that area. The open field dose rate is reduced below that of a uniformly contaminated smooth plane of infinite extent, by such factors as irregularities in the terrain, objects above ground, and effects of wind and weather.

Knapp[4] states that the open field dose rate is about 3/4 the infinite plane dose rate, that is

$$R_{OF} = R \text{ inf}$$

From the infinite plane dose rate it is possible to calculate the amount of fission products necessary to produce

such a rate three feet above a smooth infinite plane uniformly contaminated with unfractionated fission products from the thermal fission of uranium 235 at a density of one kiloton equivalent fission products per square mile, for various times after fission.[4]

For an initial deposition of 1 kiloton fission products per square mile, the dose rate at H + 12 hours is given as 152 roentgens per hour. By a simple proportion then, the contamination density for any other dose rate at H + 12 hours is

$$K = \frac{1 \times 4/3\ R_{OF}}{152}\ \text{kt/mi}^2 \text{ per r/hr}$$

Applying the $T^{-1.2}$ law for fission products decay, it is possible to calculate the contamination density for dose rates measured at times other than H + 12 hours.[5] (pp 488, 490)

$$K = \frac{4/3\ R_{OF}\ \ (12/T_0)^{-1.2}}{152}\qquad \text{kt/mi}^2 \text{ per r/hr}$$

where T_0 is the time in hours after the explosion at which the measurement R_{OF} was made.

It is assumed that the assumptions for the $T^{-1.2}$ law hold, i.e., that no additional fallout is being deposited, and that weathering does not affect the decay rate.

The amount of radioiodine produced in a nuclear explosion is roughly 1.25×10^5 curies per kiloton of fission products.[9] On the assumption that the fission debris is unfractionated, the amount of iodine 131 initially deposited is given by

$$I' = 8.77\ R_{OF} \times (12/T_0)^{-1.2} \times 1.25 \times 10^5\ \ \text{c/mi}^2 \text{ per r/hr}$$

The relevance of the fractionation assumption is difficult to assay, as very little is known about the actual mechanism of fallout phenomena. See for example the U. N. Report on the Effects of Atomic Radiation[6] (p.237), The Effects of Nuclear Weapons (p.416). The assumption of no fractionation used for this calculation follows Dunning[1] and Lapp[2].

Even though fractionation may occur, it is instructive to make the estimate based on unfractionated debris, and note that the actual levels may be lower in the areas near detonation and higher for those farther away.

The natural radioactive decay of iodine 131 (half life of 8.05 days) will reduce the amount of iodine 131 present at the time of measurement to

$$I_0 = 42.2\ R_{OF}\ (12/T_0)^{-1.2}\ e^{-.0036\ T_0}\ \mu\mu c/cm^2 \text{ per mr/hr}$$

Based on this equation a graph has been prepared showing the time dependence of iodine 131 deposition density.

B. Gross Beta on Gummed Film.

The relationship of gross beta activity to Iodine 131 activity as a function of time (as shown in Table I) has been calculated along lines essentially similar to that used in the previous section. The only change necessary is the replacement of the $T^{-1.2}$ decay law by the figures given for gross beta decay by Knapp[4].

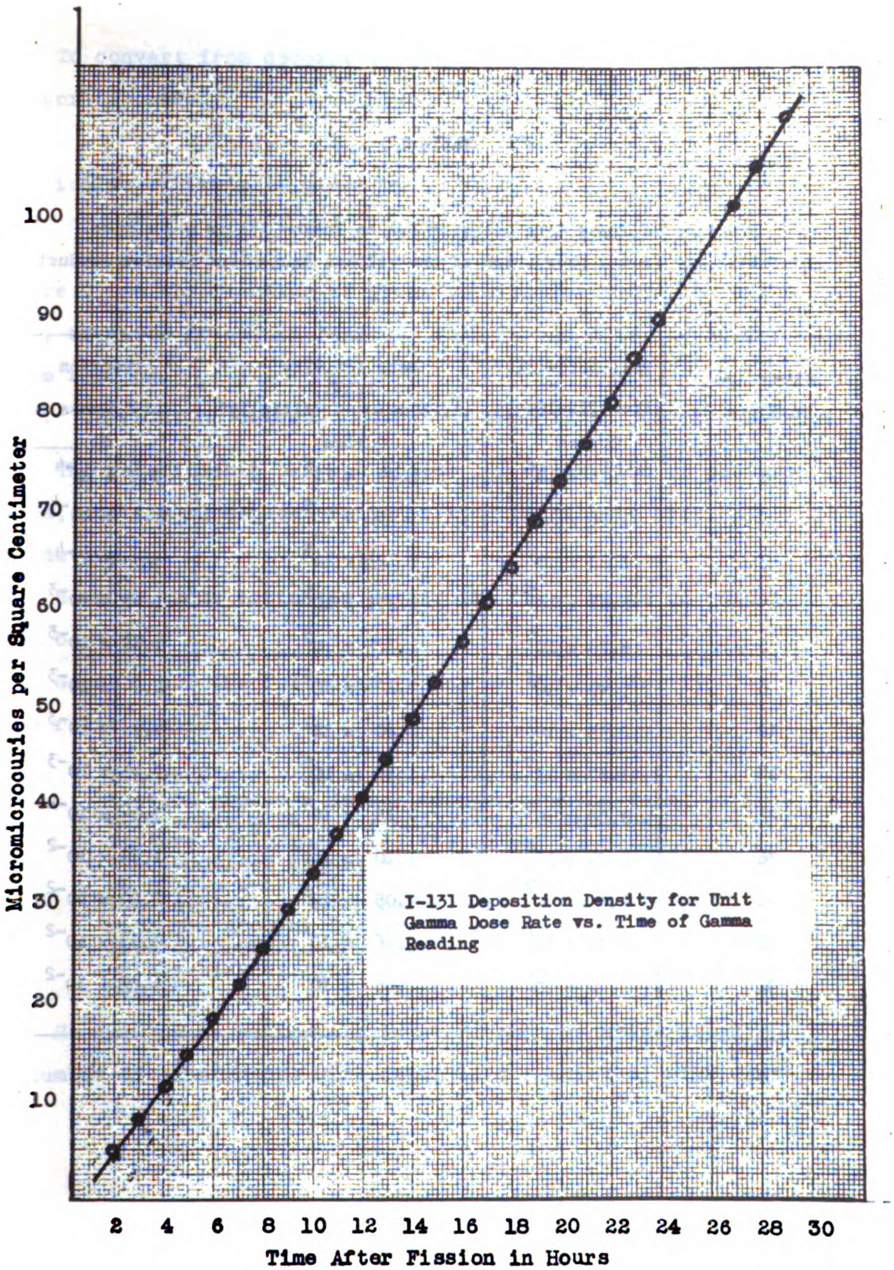

I-131 Deposition Density for Unit Gamma Dose Rate vs. Time of Gamma Reading
Micromicrocuries per Square Centimeter
100
90
80
70
60
50
40
30
20
10
2 4 6 8 10 12 14 16 18 20 22 24 26 28 30
Time After Fission in Hours

Table I

Fraction of Gross Beta Activity Due to Iodine 131 as a Function of Debris Age from a Deposition of One Kiloton Equivalent Fission Products.

Debris Age In Hours	Beta Activity (From TID-16457) Curies	Beta Activity I-131 (1.25×10^5 C Initially) Curies	Fraction I-131/Gross B St
1	4.33×10^8	1.24×10^5	2.9×10^{-4}
2	1.96×10^8	1.239×10^5	6.3×10^{-4}
3	1.22×10^8	1.1235×10^5	9.2×10^{-4}
4	8.62×10^7	1.231×10^5	1.43×10^{-3}
5	6.74×10^7	1.229×10^5	1.82×10^{-3}
6	5.49×10^7	1.22×10^5	2.2×10^{-3}
12	2.55×10^7	1.20×10^5	4.7×10^{-3}
18	1.57×10^7	1.17×10^5	7.45×10^{-3}
24	1.10×10^7	1.15×10^5	1.04×10^{-2}
36	6.74×10^6	1.10×10^5	1.63×10^{-2}
48	4.59×10^6	1.05×10^5	2.29×10^{-2}
72	2.74×10^6	9.66×10^4	3.53×10^{-2}
96	2.02×10^6	8.85×10^4	4.38×10^{-2}

To convert from decompositions per minute the following factor is used:

$$1 \ \mu\mu c = 2.22 \ d/m$$

The iodine activity is given by

$$I_0 = 1/2 \times 10^{-3} \ S_t B \ \ \mu\mu c/cm^2 \text{ per } d/m/ft^2$$

where S_t is the fraction of gross beta activity due to iodine 131, as given by column four of Table I, and B is the gummed film reading.

III. Correlation between Iodine 131 Deposition and Milk Levels.

The relationship between iodine 131 deposition on pasture area, and its subsequent concentration in milk is difficult to determine.

However, some estimates within the total range of values can be made.

Garner[7] has the following to say on the complexity of the relationship:

> "Under field conditions the extent to which fission products deposited upon grazing land will enter milk may greatly depend upon many factors including: (1) The extent to which the deposited material is initially retained on edible herbage; (2) The extent to which the initially contaminated herbage is "diluted" with new growth; (3) The extent to which the fission products are removed by rain from the edible tissues; (4) The method of animal management."

He goes on to estimate a level of contamination based on a number of experiments with controlled feeding of milk cows.

> "In order to make some estimate from the experimental data of the maximum level of contamination in milk likely to be encountered in the field, the following conditions have been assumed: (a) that 25% of the deposited material is initially retained on edible herbage; (b) that the activity on herbage decreases only as a result of the decay of radioactivity; (c) that the animals have unrestricted access to grazing and receive no supplementary food; (d) that animals consume 20 pounds dry matter a day and that the yield of edible herbage is 500 pounds dry matter per acre."

Garner's figures (See Table II) indicate that the peak milk concentration is reached two days after initial deposition and has a value of .16 $\mu c/l$ for a deposition of 1 $\mu c/m^2$ or

1 $\mu\mu c/cm^2$ deposition yields 1600 $\mu\mu c/l$ in milk.

A somewhat lower estimate can be determined from the results published by Booker[8] on the Windscale reactor accident.

Two factors of particular interest can be determined from Booker's data:

(1) The percentage of the total iodine 131 deposition retained on edible herbage.

(2) The correlation between iodine 131 on edible herbage and the subsequent iodine levels in fresh milk.

To determine the retention factor consider the following data: The effective half life of iodine 131 in herbage at Seascale is given as

$$T_e = 4.9 \text{ days}$$

Further, on October 28th, seventeen days after the accident, the percentage of iodine 131 still in the herbage is given as 16 per cent.

In order to determine the effect of weathering, consider the total decay of iodine 131 on herbage:

$$I = I_1 e^{-\lambda_{eff} t}$$

This decay is due both to radioactive decay and to effects of weathering. Hence

$$I = I_1 e^{-\lambda_{eff} t} = I_1 e^{-\lambda_r t} e^{-\lambda_w t}$$

so that
$$\lambda_w = \lambda_{eff} - \lambda_r$$

and the weathering half life is thus calculated to be,

$$T_w = \ln 2/\lambda_w = \ln 2/\ (5.5 \times 10^{-2}) = 12 \text{ days}$$

If I_T is the total iodine 131 activity, including both iodine 131 on the herbage and on the soil, then

$$I_H(17) = .16\ I_T$$
$$= I_1 e^{-\lambda_w 17}$$

$$\text{and } I_1/I_T = .406$$

This means that 40 percent of the initial deposition was retained on edible herbage.

Booker concludes from the analysis of his data that an iodine 131 activity of 1 $\mu c/m^2$ on edible herbage leads to milk levels of 0.1 $\mu c/l$.

Combining this result with the calculations of the retention factor yields the result that a deposition of 1 $\mu\mu c/cm^2$ gives a milk concentration of 400 $\mu\mu c/l$.

These estimates give some indication of the range over which milk levels may vary. It is assumed that the dairying

conditions are sufficiently similar between the U. S. and England to permit the use of Booker's results in the calculations of this report.

Summarizing the results of this section;

(1) Estimate based on Windscale
$T_{eff} = 4.9$ days
$1\ \mu\mu c/cm^2 \longrightarrow 400\ \mu\mu c/l$

(2) Estimate based on Garner
$T_{eff} = 8.05$ days
$1\ \mu\mu c/cm^2 \longrightarrow 1600\ \mu\mu c/l$

IV. Infant Thyroid Dose Calculations.

The dose to the thyroid from a daily ingestion of contaminated milk is normally determined in the following manner. Let the instantaneous concentration of iodine in the thyroid be X (t). If the iodine concentration in the milk is I (t), and the fraction of this iodine taken up by the thyroid is r, then the concentration in the thyroid as a function of time is described by the differential equation,

$$\frac{d}{dt} X(t) = r\,I(t) - \lambda_b X(t)$$

where $_b$ is the decay constant for elimination of iodine from the thyroid (composite of radioactive and biological half lives).

The general solution to this equation is

$$X(t) = e^{-\lambda_b t} \int_o^t e^{\lambda_b t}\, rI(t)\, dt + X(o)\, e^{-\lambda_b t}$$

For a milk concentration decreasing with a half life of T_M (decay constant of λ_M)

$$I(t) = I'e^{-\lambda_M t}$$

The thyroid concentration is

$$X(t) = \frac{rI'}{\lambda_b - \lambda_M} \left(e^{-\lambda_M t} - e^{-\lambda_b t} \right)$$

(The iodine concentration at t= 0 was assumed to be zero.)

The total thyroid dose from the continued consumption of such milk is:

$$D = \int_0^\infty \frac{k\,X(t)}{m}\,dt$$

$$= \frac{krI'}{m\,\lambda_b\,\lambda_m}$$

The values used for the constants are

k = 1.08 x_{10}^{-5} rads/day per $\mu\mu c/gm$

r = .30 uptake of ingested iodine

m = 2 grams for infant thyroid

b = 9.12 x 10^{-2} $days^{-1}$ (T_b = 7.6 days)

The total dose is then

$$D = 1.78 \times 10^{-5} \frac{I}{\lambda_M} \text{rads}$$

The two estimates of milk levels determined in Section III for a deposition of 1 $\mu\mu c/cm^2$

(1) Windscale Data

M = 14.1 x 10^{-2} $days^{-1}$

I'= 400 uuc/l per $\mu\mu c/cm^2$

D = .05 rads per $\mu\mu c/cm^2$

(2) Garner's Data

$$\lambda_M = 8.60 \times 10^{-2} \text{ days}^{-1}$$

$$I' = 1600 \ \mu\mu c/l \text{ per } \mu\mu c/cm^2$$

$$D = .33 \text{ rads per } \mu\mu c/cm^2$$

These values can be used, then, to estimate the total dose to an infant thyroid from the external gamma, or gross beta measurements in the grazing area.

Table II

(From R. J. Garner in Nature, 186:1963)

Estimated Activity in Milk (μC./L.)
Following an Initial Total Deposition of 1 μC./M.^{2}

Days after Deposition	I-131	I-131	Te-132	Sr - 90	Sr -90	Ba - 140	Cs - 137
1	0.12	0.060	0.0029	0.006	0.006	0.0028	0.01
2	0.16	0.038	0.0072	0.014	0.015	0.0058	0.06
3	0.16	0.019	0.0090	0.020	0.021	0.0075	0.14
4	0.15	0.009	0.0090	0.023	0.025	0.0085	0.21
5	0.15	0.004	0.0082	0.025	0.027	0.0090	0.26
6	0.14	0.002	0.0071	0.026	0.028	0.0092	0.29
7	0.13	0.001	0.0059	0.027	0.029	0.0092	0.32
8	0.12	—	0.0049	0.027	0.030	0.0091	0.35
9	0.11	—	0.0040	0.027	0.030	0.0089	0.36
10	0.10	—	0.0033	0.027	0.030	0.0086	0.39
21	0.04	—	—	0.023	0.031	0.0049	0.48

REFERENCES

1. Dunning, Gordon, in "Biological and Environmental Effects of Nuclear War." Hearings before a subcommittee of the Joint Committee on Atomic Energy, June 22-26, 1959, pp. 436-471.

2. Lapp, Ralph, "Nevada Test Fallout and Radioiodine in Milk." Science, 137. 756, 1962.

3. Pendleton, R. C., C. W. Mays, R. D. Lloyd and A. L. Brooks. "Iodine-131 in Utah During July and August 1962," 1962, Science, 141:640, 1963.

4. Knapp, H. A., "Gamma Ray Exposure Dose to Non-urban Populations from the Surface Deposition of Nuclear Test Fallout." T.I.D. 16457. Fallout Studies Branch.

5. Glasstone, Samuel, ed., The Effects of Nuclear Weapons. U. S. Dept. of Defense. Washington, D. C. Revised 1962.

6. Report of the United Nations Scientific Committee on the Effects of Atomic Radiation. New York, 1962.

7. Garner, R. J., "An Assessment of the Quantities of Fission Products Likely to be Found in Milk in the Event of Aerial Contamination of Agricultural Land." Nature, 186:1963, June 25, 1960.

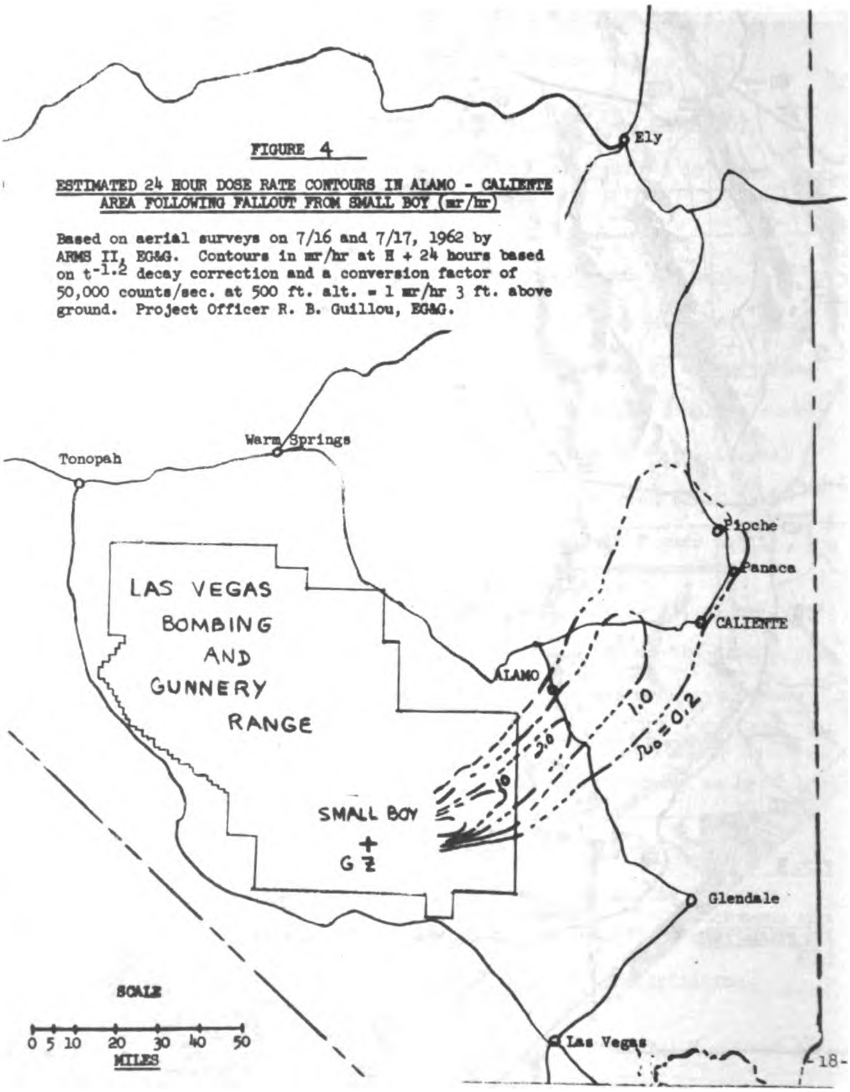
8. Booker, D. V., "Physical Measurements of Activity in Samples from Windscale." United Kingdom Atomic Energy Authority Research Groups. Harwell, 1958.

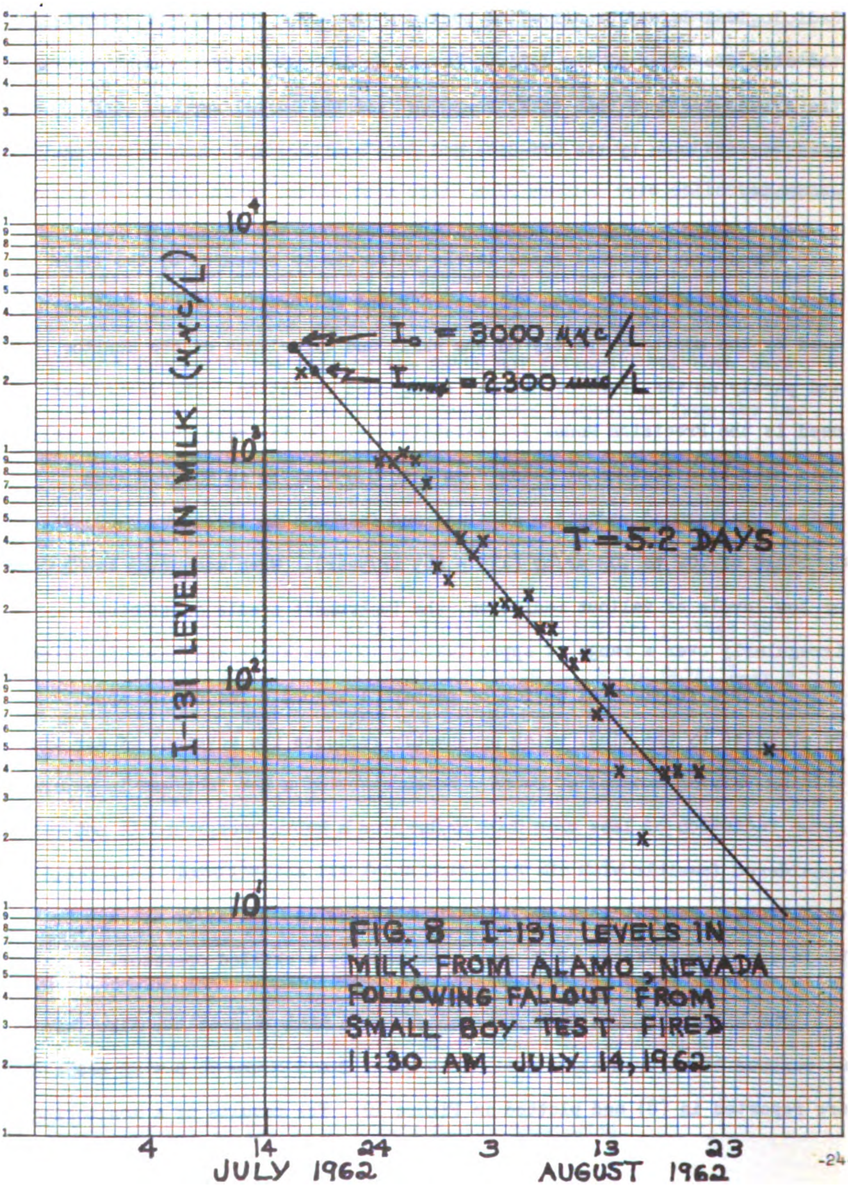
9. USNRDL-TR-425, A Theory of Formation of Fallout From Land-Surface Nuclear Detonations and Decay of the Fission Products, C. F. Miller, 27 May, 1960.

FIGURE 4

ESTIMATED 24 HOUR DOSE RATE CONTOURS IN ALAMO - CALIENTE AREA FOLLOWING FALLOUT FROM SMALL BOY (mr/hr)

Based on aerial surveys on 7/16 and 7/17, 1962 by ARMS II, EG&G. Contours in mr/hr at H + 24 hours based on $t^{-1.2}$ decay correction and a conversion factor of 50,000 counts/sec. at 500 ft. alt. = 1 mr/hr 3 ft. above ground. Project Officer R. B. Guillou, EG&G.




I-131 LEVEL IN MILK (μμc/L)
I_0 = 3000 μμc/L
I_{max} = 2300 μμc/L
T = 5.2 DAYS
FIG. 8 I-131 LEVELS IN MILK FROM ALAMO, NEVADA FOLLOWING FALLOUT FROM SMALL BOY TEST FIRED 11:30 AM JULY 14, 1962
4
14
24
3
13
23
JULY 1962
AUGUST 1962

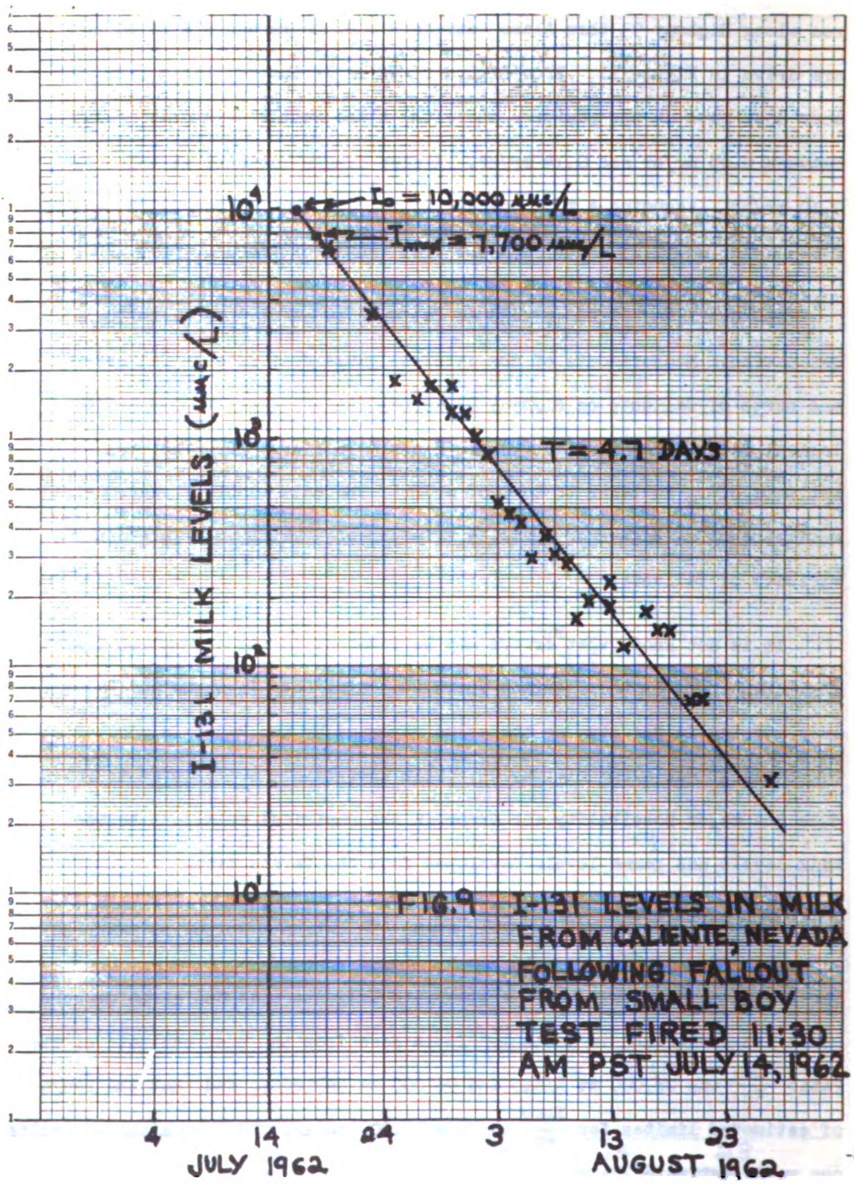


FIG. 9 I-131 LEVELS IN MILK FROM CALIENTE, NEVADA FOLLOWING FALLOUT FROM SMALL BOY TEST FIRED 11:30 AM PST JULY 14, 1962

-26-

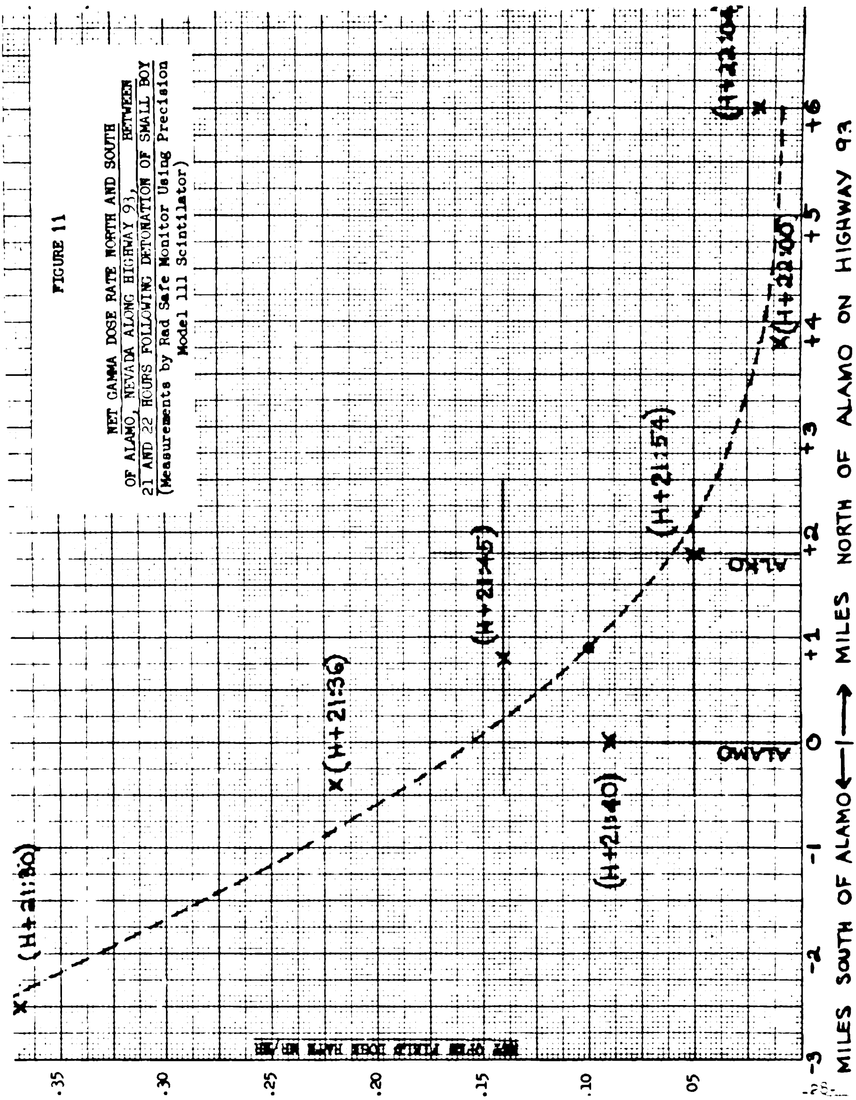
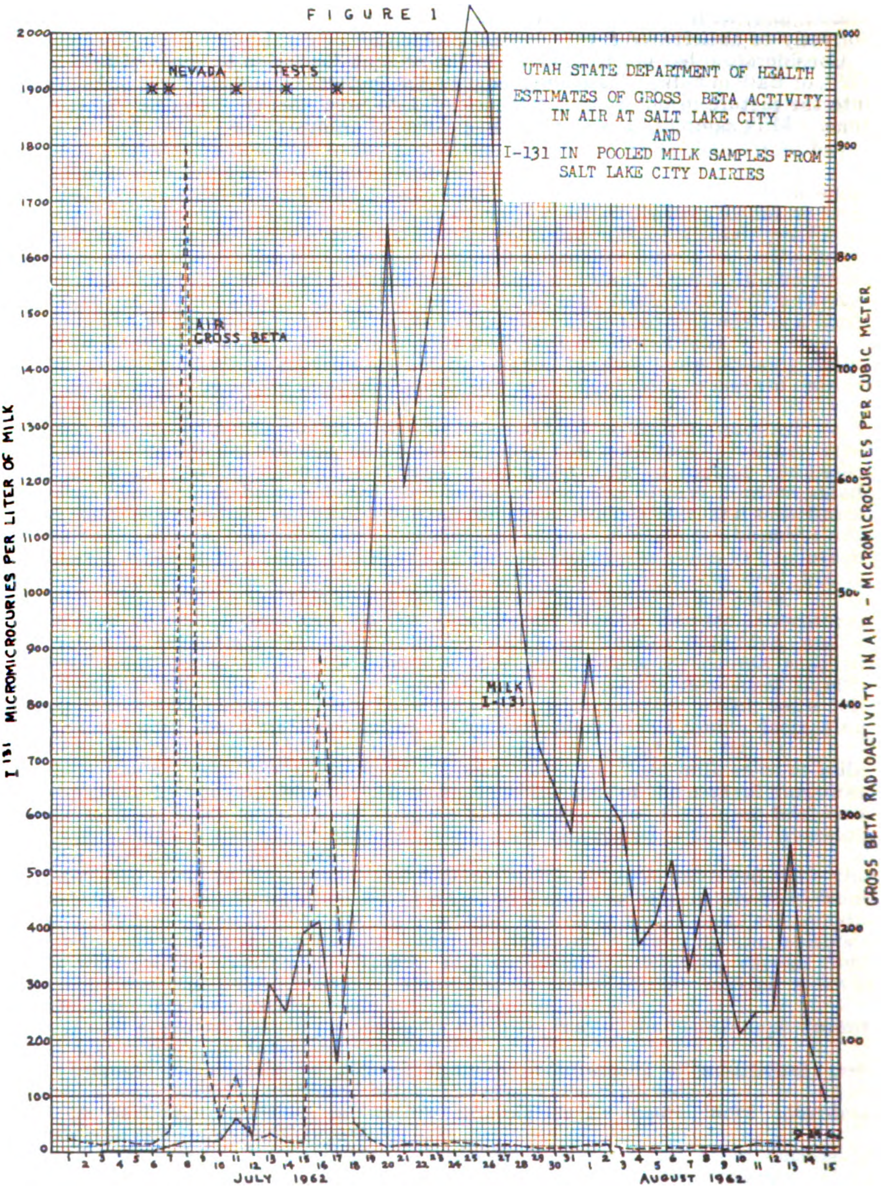


FIGURE 11
NET GAMMA DOSE RATE NORTH AND SOUTH OF ALAMO, NEVADA ALONG HIGHWAY 93, BETWEEN 21 AND 22 HOURS FOLLOWING DETONATION OF SMALL BOY
(Measurements by Rad Safe Monitor Using Precision Model 111 Scintilator)
(H+21:30)
(H+21:36)
(H+21:40)
(H+21:45)
(H+21:54)
(H+22:00)
(H+22:04)
ALAMO
ALKO
.35
.30
.25
.20
.15
.10
.05
-3
-2
-1
0
+1
+2
+3
+4
+5
+6
MILES SOUTH OF ALAMO ← | → MILES NORTH OF ALAMO ON HIGHWAY 93
-28-

FIGURE 1


UTAH STATE DEPARTMENT OF HEALTH
ESTIMATES OF GROSS BETA ACTIVITY IN AIR AT SALT LAKE CITY AND I-131 IN POOLED MILK SAMPLES FROM SALT LAKE CITY DAIRIES
NEVADA TESTS
AIR GROSS BETA
MILK I-131
I 131 MICROMICROCURIES PER LITER OF MILK
GROSS BETA RADIOACTIVITY IN AIR - MICROMICROCURIES PER CUBIC METER
JULY 1962
AUGUST 1962

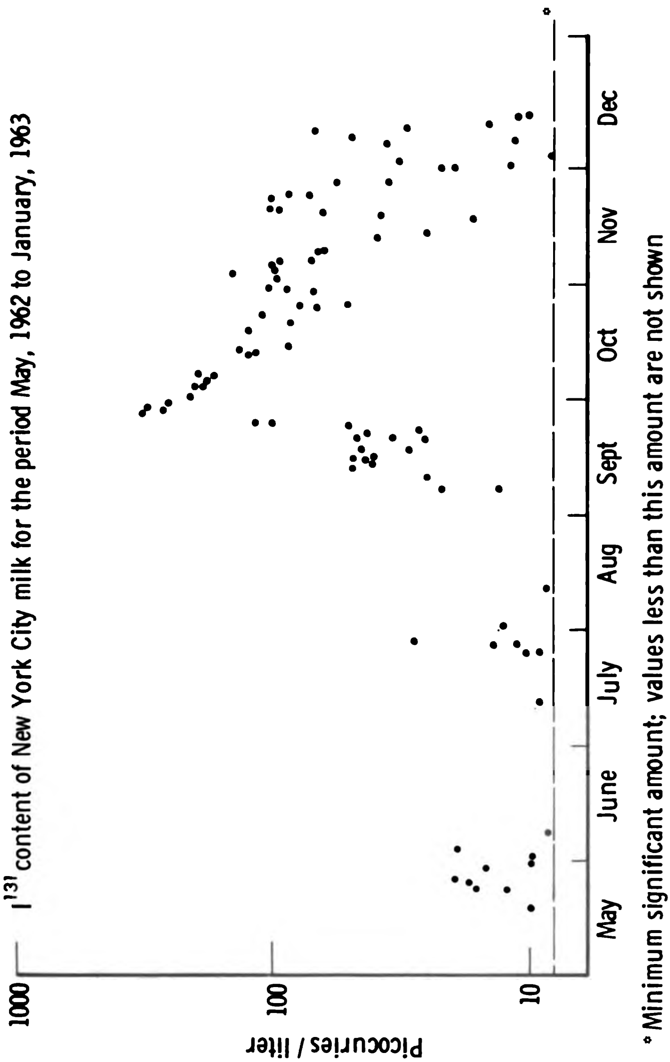
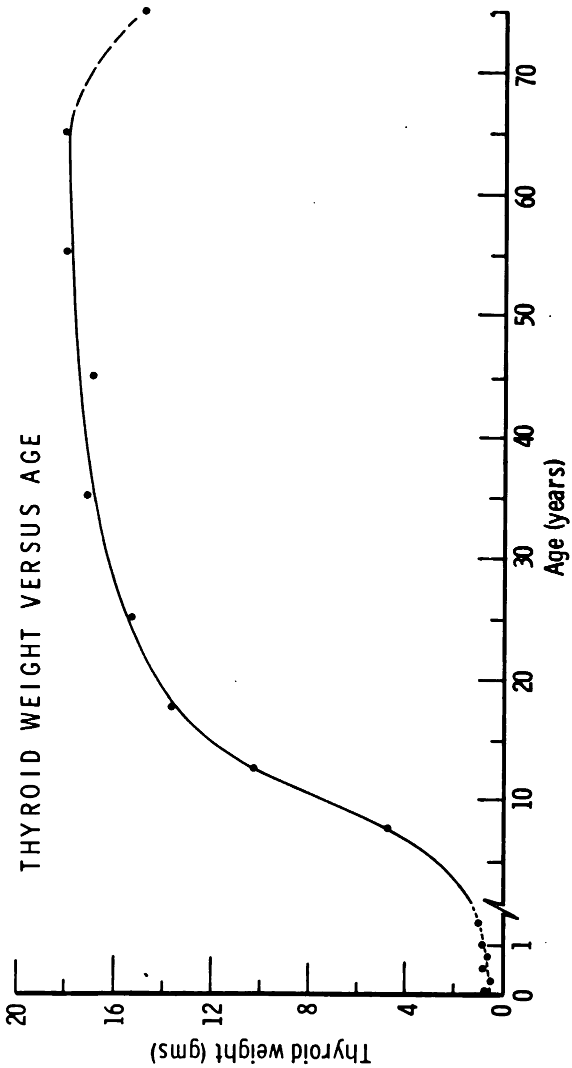
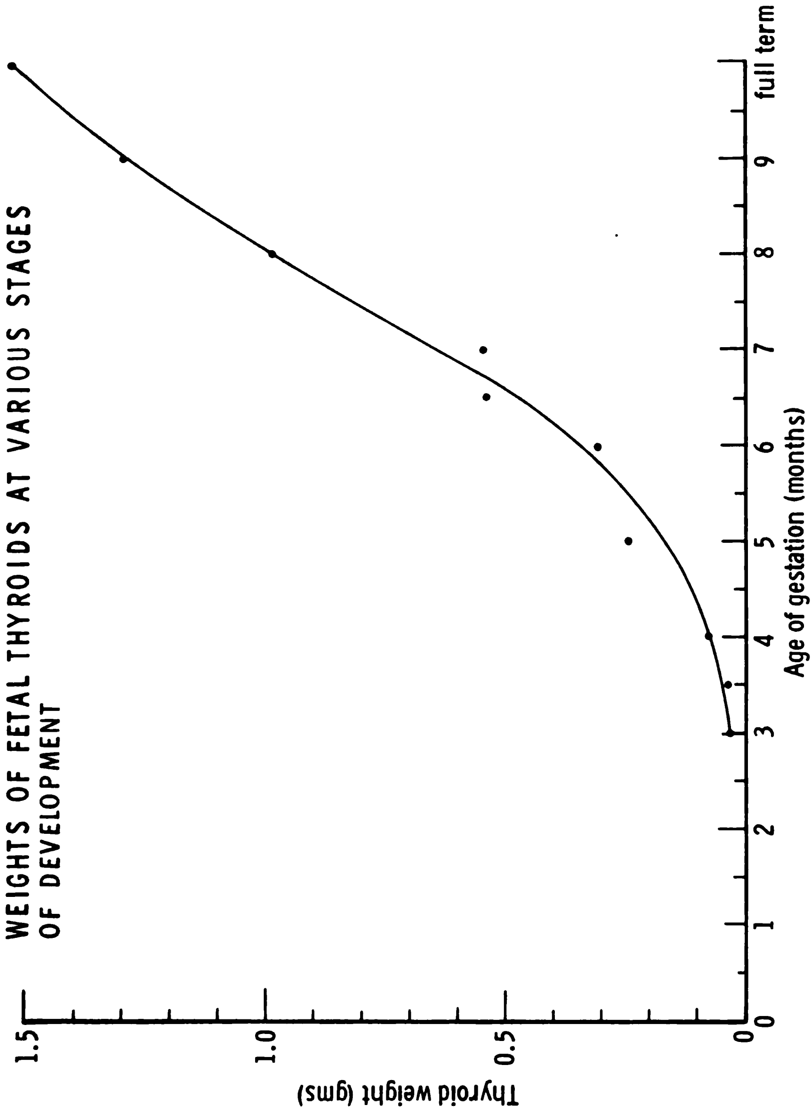


FIGURE 1

20-519 O - 63 - pt. 2 - 44


THYROID WEIGHT VERSUS AGE
Thyroid weight (gms)
0
4
8
12
16
20
Age (years)
0
1
10
20
30
40
50
60
70



20-519 O - 63 - pt. 2 - 45

Fig. 2 Log-normal probability plot of thyroid weights